GENERAL ATOMIC

DIVISION OF GENERAL DYNAMICS

GA-4782

41p.

N64-19601 *

CODE-1

NASA CR-53779

ABUNDANCES OF Na, Sc, Cr, Mn, Fe, Co, AND Cu IN 92 METEORITES, 9 TERRESTRIAL SPECIMENS, AND 90 INDIVIDUAL CHONDRULES

QUARTERLY PROGRESS REPORT

FOR THE PERIOD ENDING NOVEMBER 30, 1963

Contract NASw-843

National Aeronautics and Space Administration

OTS PRICE

XEROX $ 4.60 ph

MICROFILM $ ~~1.61 mf.~~

December 17, 1963

GENERAL ATOMIC Div,

DIVISION OF

102 8612 GENERAL DYNAMICS,

JOHN JAY HOPKINS LABORATORY FOR PURE AND APPLIED SCIENCE

P.O. BOX 608. SAN DIEGO 12, CALIFORNIA

N64-19601
Code-1

(NASA CR-53779; GA-4782) OTS: See Cover

ABUNDANCES OF Na, Sc, Cr, Mn, Fe, Co, AND Cu IN 92 METEORITES, 9 TERRESTRIAL SPECIMENS, AND 90 INDIVIDUAL CHONDRULES

QUARTERLY PROGRESS REPORT; Nov. 30, 1963

FOR THE PERIOD ENDING NOVEMBER 30, 1963

(NASA Contract NASw-843)

National Aeronautics and Space Administration

Work done by:

R. A. Schmitt
R. H. Smith

Report written by:

R. A. Schmitt and
R. H. Smith 17 Dec. 1963

47p refs

December 17, 1963

PREVIOUS REPORTS IN THIS SERIES

GA-2782 (Rev.)—Quarterly Report, September 15, 1961, through December 15, 1961

GA-2985—Quarterly Report, December 15, 1961, through March 15, 1962

GA-3212—Quarterly Report, March 15, 1962, through June 15, 1962

GA-3411—Summary Report, September 15, 1961, through August 14, 1962

GA-3687—Quarterly Report, August 15, 1962, through November 30, 1962

GA-3961—Quarterly Report, December 1, 1962, through February 15, 1963

GA-4221—Quarterly Report, February 15, 1963, through May 15, 1963

GA-4493—Summary Report, August 15, 1962, through August 31, 1963

CONTENTS

INTRODUCTION

This progress report in the third year of research on elemental abundances in meteoritic and terrestrial materials covers the contract period from September 1 through November 30, 1963. Previous work on this program was done under Contracts NASw-75 and NASw-579.

During this quarter, abundances of seven elements--Na, Sc, Cr, Mn, Fe, Co, and Cu--were determined by the technique of instrumental neutron activation analysis (INAA) in over 50 meteoritic specimens, 4 terrestrial specimens, and 90 individual chondrules separated from 4 chondritic meteorites. This research was performed in collaboration with G. G. Goles of the University of California at San Diego. The meteoritic and terrestrial samples were obtained from various sources. The majority of chondritic meteorites were obtained from Carleton B. Moore of the Nininger Meteorite Collection and Arizona State University. Many others were obtained from H. E. Suess of the University of California at San Diego, B. H. Mason of the American Museum of Natural History, E. P. Henderson of the Smithsonian Institution, and E. Olsen of the Chicago Natural History Museum. Sources of still other specimens have been acknowledged in previous reports of this series.

During the quarter, a paper entitled "Implications of Similarity in Rare-earth Fractionation of Nakhlitic Meteorites and Terrestrial Basalts," by R. A. Schmitt and R. H. Smith, was published in Nature (Vol. 199, pp. 550-551, August 10, 1963). Another paper entitled "Abundances of Na, Sc, Mn, Cr, Fe and Co in Stony Meteorites via Instrumental Neutron Activation Analysis" was presented by R. A. Schmitt and G. G. Goles at the Second National Meeting of the Society for Applied Spectroscopy, San Diego, October 14-18, 1963.

Two abstracts have been submitted for presentation at the meeting of the American Association for the Advancement of Science in Cleveland, December 26-30, 1963: "Instrumental Neutron Activation Analysis of Chondritic Meteorites and Some Geochemical Implications," by G. G. Goles and R. A. Schmitt, and "Abundances of Na, Sc, Cr, Mn, Fe, Co, and Cu in Individual Meteoritic Chondrules by Instrumental Neutron Activation Analysis," by R. A. Schmitt, R. H. Smith, and G. G. Goles.

COMMENTS ON THEORIES OF THE ORIGIN OF METEORITES AND CHONDRULES

Up to the present time, the authors have determined abundances of the 14 rare-earth elements (REE) plus Sc and Y in 35 meteorites covering the entire meteoritic spectrum and in 5 terrestrial specimens. In order to adequately correlate these abundances with any meteoritic model, it is absolutely necessary to ascertain the REE, Sc, and Y abundances in more achondrites (both Ca-rich and Ca-poor), in chondrules, and in specific chondritic minerals, such as olivines and pyroxenes. To theorize in detail without such additional data for these sensitive elements would be to enlarge unnecessarily the speculative aspect of the meteoritic literature. The authors believe, however, that the present REE data seem to be generally best satisfied by Urey's model(1) of many-body involvements. Briefly, the two principal reasons for this belief are the general polymict and conglomerate character of chondrites and the observed(2)(3) nonfractionation of the 14 REE in 20 chondritic meteorites. After the REE have been determined in chondrules, individual minerals, and many more achondrites, the authors will attempt a correlation of the REE abundances and meteoritic model(s).

At present, the chemical constituency of individual chondrules is known for only a few elements and for only a few meteorites. Some of the most recent quantitative measurements include the microprobe work by Fredriksson and Keil(4)(5) on the Fe, Mg, and Ca contents in selected chondritic mineral grains; the INAA determination by the present authors of the abundances of 7 elements in individual chondrules from 4 chondrites; and Wood's mineralogical studies(6)(7) of chondrules from chondritic matrices. In the opinion of the authors and their collaborators, only one fact about chondrules is fairly certain, namely, that the past history of chondrules included a glassy stage. Only after the chemical and mineralogical constituencies of many chondrules from many chondrites extending over the chondritic classification spectra have been ascertained will theories of chondrule origin become at all meaningful. To attempt theories of chondrule origin with the present paucity of data is analogous to attempting a theory of the nucleus with a handful of neutron and proton cross sections.

Moreover, the authors and their collaborators will deliberately refrain from offering any new theories concerning the origins of meteorites because of the lack of accurate data on many critical trace elements. It is our contention that theories about meteoritic origins will become meaningful only after the abundances of many more trace elements are ascertained accurately in nonchondritic meteorites. The fact that Ca-rich achondrites are about 10 times richer in such trace elements as Ba, U, Th, the REE, Sc, and Y than are ordinary chondrites but are apparently not enriched in Zr certainly affects the "cosmic" abundance curve if all meteorites are considered in any comprehensive theory.

EXPERIMENTAL

INAA OF Na, Sc, Cr, Mn, Fe, Co, AND Cu IN CHONDRITES AND TERRESTRIAL MATTER

The procedure for determination of Na, Sc, Cr, Mn, Fe, Co, and Cu in chondrites has been described on page 4 of Ref. 8. All analyses performed in this quarter utilized this procedure. About 25 meteorite samples of ~0.1 to 0.5 g each and 1 standard, ~1-ml, each of Na, Mn, and Cu were placed in 2-dram vials and irradiated simultaneously in the rotating rack of the TRIGA reactor for 10 min at a flux of $\sim 10^{11}$ neutrons/cm^2/sec. After irradiation the meteorites were transferred to new 2-dram vials. About 12 drops of the irradiated standards were pipetted into weighed, new 2-dram vials. Reweighing of the new vials then yielded the exact quantity of the standards. Gamma-ray geometries were identical for the standards and meteorites. Counting commenced about 3 hr after irradiation, with the Mn abundance being determined first via the 0.85-Mev gamma ray (γ) of 2.56-h Mn^{56} by counting the samples in an elevated geometry. Counting rates were held to <150,000 pulses/min to obviate drift problems. After ~24 hr of decay (Mn^{56} decays by a factor of $\sim 10^{-3}$ during this interval), Na and Cu abundances were found via the 2.75-Mev γ of 15-h Na^{24} and the 0.51-Mev annihilation γ of 12.8-h Cu^{64}. Usually the samples were counted directly on a 3 in. by 3 in. NaI(Tl) solid crystal. The contribution of Na^{24} 0.5-Mev annihilation γ's due to interactions of the high-energy γ's of Na^{24} with the sample, lead shield, etc., to the total 0.5-Mev γ peak of Cu^{64} positron annihilation was conveniently subtracted by finding the ratio of the 0.5-Mev γ peak area to the 2.75-Mev γ peak area of the Na^{24} standard. From the observed 2.75-Mev γ peak of the meteoritic or terrestrial specimen, and the observed standard ratio, the Na^{24} contribution was subtracted. Contributions to the 0.51-Mev γ peak area from other radionuclides were negligible compared with the Na^{24} contribution. It is noted that the Cu abundances determined by the INAA technique agreed well[8] with those found by Smales, et al.,[9] who used radiochemical techniques in which Cu^{64} was separated from the entire irradiated meteoritic matrix and counted separately.

Furthermore, to check on the certainty of Mn^{56}, agreement was required for the ratio of the 0.85-Mev/1.81-Mev γ peaks for the meteorites and Mn^{56} standard. For Na^{24}, ratios of the peak heights of 1.37- and 2.75-Mev γ's for samples and standards were checked, and for Cu^{64}, the decay of the peak area (Na^{24} subtracted for each value) had to conform to a 12.8-h half-life. For critical Cu abundances in Orgueil and Ivuna (Type I carbonaceous chondrites), Cu^{64} decays were checked, whereas for other meteorites Cu^{64} decays were randomly checked. Typical gamma-ray spectra are given in the previous quarterly report.(8) Abundances were calculated via the peak-area method as given by a multichannel printer.

After a few days of decay, the specimens and reference standards of Sc, Cr, Fe and Co were reirradiated in a flux of 2×10^{12} neutrons/cm^2/sec for 30 min.. Following a decay of ~2 weeks, the samples and standards were transferred to new vials as described above. Pulse-height spectra(8) of the gamma rays yielded the abundances of Cr via 28-d Cr^{51}, 0.32 Mev; Fe via 45-d Fe^{59}, 1.10 and 1.29 Mev composite; Sc via 85-d Sc^{46}, 2.01 Mev sum peak; and Co via 5.3-y Co^{60}, 2.50 Mev sum peak. Specimens and standards were counted on a 3 in. by 3 in. NaI(Tl) solid crystal in identical geometries. Self-absorption and other corrections for samples and standards were negligible.

For 28-d Cr^{51}, 18 randomly chosen chondrites after a ~46-day decay period showed no appreciable contamination, say ~5% contribution of some long-lived component, not necessarily 74-d Ir^{192}. Ir^{191} has an appreciable cross section for thermal-neutron absorption; this possible source of error was pointed out by W. D. Ehmann of the University of Kentucky.

Abundances of Fe were calculated via the 1.10- and 1.29-Mev composite γ's of 45-d Fe^{59} after subtraction of the peak areas of the 1.12-Mev γ of 85-d Sc^{46} and the 1.17- and 1.33-Mev γ's of 5.3-y Co^{60}. Ratios of the peak areas of the 1.12-Mev γ to the 2.01-Mev sum γ's of Sc^{46} and 1.17- and 1.33-Mev γ's to the 2.50-Mev sum γ's of Co^{60} were obtained via the Sc^{46} and Co^{60} reference standards under identical counting geometries. The total errors for all total Fe values obtained by INAA reflect the total statistical errors due to Fe^{59}, Sc^{46}, and Co^{60} and also the errors in the ratios of the Sc^{46} and Co^{60} gamma-ray peaks.

Fe values obtained via INAA agree well with those determined by other analyses (see Table 1). INAA of known and varying quantities of Fe, Sc, and Co given in Table 9* presents further convincing evidence that Fe abundances may be determined to better than ±6%.

Analyses of small quantities, e.g., 52 mg for Santa Cruz and 30 mg for Alais, were predicated on the limited availability of some meteorites. In general, it was felt that quantities of ~0.2 g for chondritic meteorites should give fairly accurate abundances, at least to ±5%. It is the authors' contention that abundance values accurate to ±1% for an entire meteorite, which may be obtained from large samples of 10 to 20 g, are not necessarily required, since differences in elemental abundances between meteorites

*All tables appear at the end of the report.

within a chondritic group and from group to group are generally much larger than 1%. From analysis of the chondrites listed in Tables 1 and 2, the rough mean deviation of a particular elemental abundance in 49 ordinary chondrites was found to be $\sim\pm10\%$. As shown in Table 1, duplicate and sometimes triplicate analyses showed mean deviations of $\sim3\%$ to 5%. Each individual analysis was generally accurate to $\pm2\%$ to 3% (error due to counting statistics). In future analyses, sample size will be increased from 0.5 to 1 g whenever possible. INAA of nonchondritic meteorites demands larger sample sizes owing to the heterogeneity of this type of meteorite (as the data of Table 1 indicate).

INAA OF Na, Sc, Cr, Mn, Fe, Co, AND Cu IN INDIVIDUAL CHONDRULES

Individual chondrules from several meteorites have been analyzed for Na, Sc, Cr, Mn, Fe, Co, and Cu by INAA. In the first attempt at the separation of individual chondrules from a meteorite (Ochansk), the meteoritic material was crushed in a small vise; this procedure proved too drastic and many of the chondrules were broken. In subsequent work involving the collection of chondrules, the meteoritic material was picked apart under a microscope, using tweezers and a scalpel knife specially reserved for this purpose.

After the chondrules had been separated from the main mass of meteoritic material, they were cleaned. This involved holding each chondrule in the field of a microscope, removing any extraneous mineral matter from its surface by scraping with the scalpel, and finally brushing with a fine camel's-hair brush to remove dust and fine rock debris. The chondrules were then separated into magnetic and nonmagnetic fractions by using a small magnet covered with smooth paper for easy recovery of the magnetic chondrules. Klaus Keil of the University of California at San Diego examined the first group of separated chondrules to verify that the chondrules were real and not artifacts. In physical appearance, most of the chondrules were rounded although some were pear-shaped or even irregular in form. They were commonly about 0.1 to 2 mm in diameter. Broken surfaces on orthopyroxene chondrules usually revealed prisms or plates radiating from a point which was eccentric and not central. Broken surfaces on olivine chondrules usually revealed a granular or even a barred structure.

Selected chondrules were placed in 2-dram polyvials (magnetic chondrules in one polyvial and nonmagnetic chondrules in a second polyvial) and then irradiated, together with Na, Mn, and Cu reference standards, in the rotating rack of the TRIGA reactor in a flux of $\sim2 \times 10^{12}$ neutrons/cm^2/sec.. Usually a 30-min irradiation was used for Na, Mn, and Cu followed by a 2-hr irradiation (after the chondrules were counted for Na, Mn, and Cu) for Sc, Cr, Fe, and Co.

After irradiation each chondrule was weighed and then placed in a separate, clean, 2-dram polyvial. Aliquots of the irradiated standards were weighed into clean 2-dram polyvials and then evaporated down to a small drop under a heat lamp to obtain the same counting geometry for the standards as for the chondrules.

The individual chondrules were counted on a 100 or 256 multichannel analyzer. Counting for Na^{24}, Mn^{56}, and Cu^{64} activities was performed soon after the irradiation, using a 3 in. by 3 in. NaI(Tl) solid crystal. Counting for Sc^{46}, Cr^{51}, Fe^{59}, and Co^{60} was done after a decay period of at least 2 weeks in order to circumvent interference from Na^{24} activity. A 3 in. by 3 in. NaI(Tl) well crystal was used to enhance the sum peaks of Sc^{46} and Co^{60}. Gamma-ray spectra were similar to those obtained from neutron-irradiated chondrites. Abundances were calculated from peak areas of prominent gamma rays as described above for INAA of chondrites.

RESULTS AND DISCUSSION FOR ABUNDANCES OF Na, Sc, Cr, Mn, Fe, Co, AND Cu IN WHOLE-ROCK-TYPE METEORITES AND TERRESTRIAL MATTER

Table 1 contains abundance values of Na, Sc, Cr, Mn, Fe, Co, and Cu determined by INAA in 76 chondritic, 16 nonchondritic, and 9 terrestrial specimens. Values without indicated errors are certainly accurate to better than ±10% and generally have an error of only ±5%. All values for meteoritic and terrestrial abundances given in the previous quarterly report, (8) which account for about a third of the current total, have been included in Table 1 for completeness and convenience. All meteorites have been classified according to Prior, (10) Mason, (11) Urey and Craig, (12) and Keil. (13) In Column 1, Fa and Fi indicate observed falls and finds, respectively, followed by the appropriate Rose-Tschermak-Brezina classification. (12) Values in parentheses were obtained by other workers. Values qualified by (out) have been excluded in average computations.

Histograms of the abundances of the elements Na, Sc, Cr, Mn, Fe, Co, and Cu in the H- and L-group ordinary chondrites are given in Figs. 1 through 7, respectively. In Figs. 8 and 9, histograms of Na and Mn distributions in chondrules have been compared with the distributions of the respective element in ordinary whole-rock-type chondrites.

In Table 2, the average meteoritic and terrestrial abundances of Na, Sc, Cr, Mn, Fe, Co, and Cu in the various meteorite classifications as determined by INAA have been compiled. Table 3 lists the abundances of these elements as a function of chondritic subclass and of H- or L-group.

The abundances determined for each element are discussed below.

1. Na. From Table 1 it is seen that the values of Edwards and Urey (14) may be considered the most reliable of previous Na determinations. For the carbonaceous meteorites, the $Na/10^6 Si$ atomic ratio decreases uniformly from Type I to Type III, while the atomic ratios in the other four chondritic categories (H-, L-, and LL-(Soko-Banja) groups and enstatitic) are rather uniform. The atomic ratio for the Type II carbonaceous chondrites correlates best with that for the noncarbonaceous chondrites. Furthermore, the Na abundances in Type I Orgueil and Ivuna are essentially identical, whereas in Alais, another Type I chondrite, the Na abundance is lower by ~10%. However, the Na error for Alais is ~±5% and the quantity of the analyzed sample of Alais was small at 30 mg.

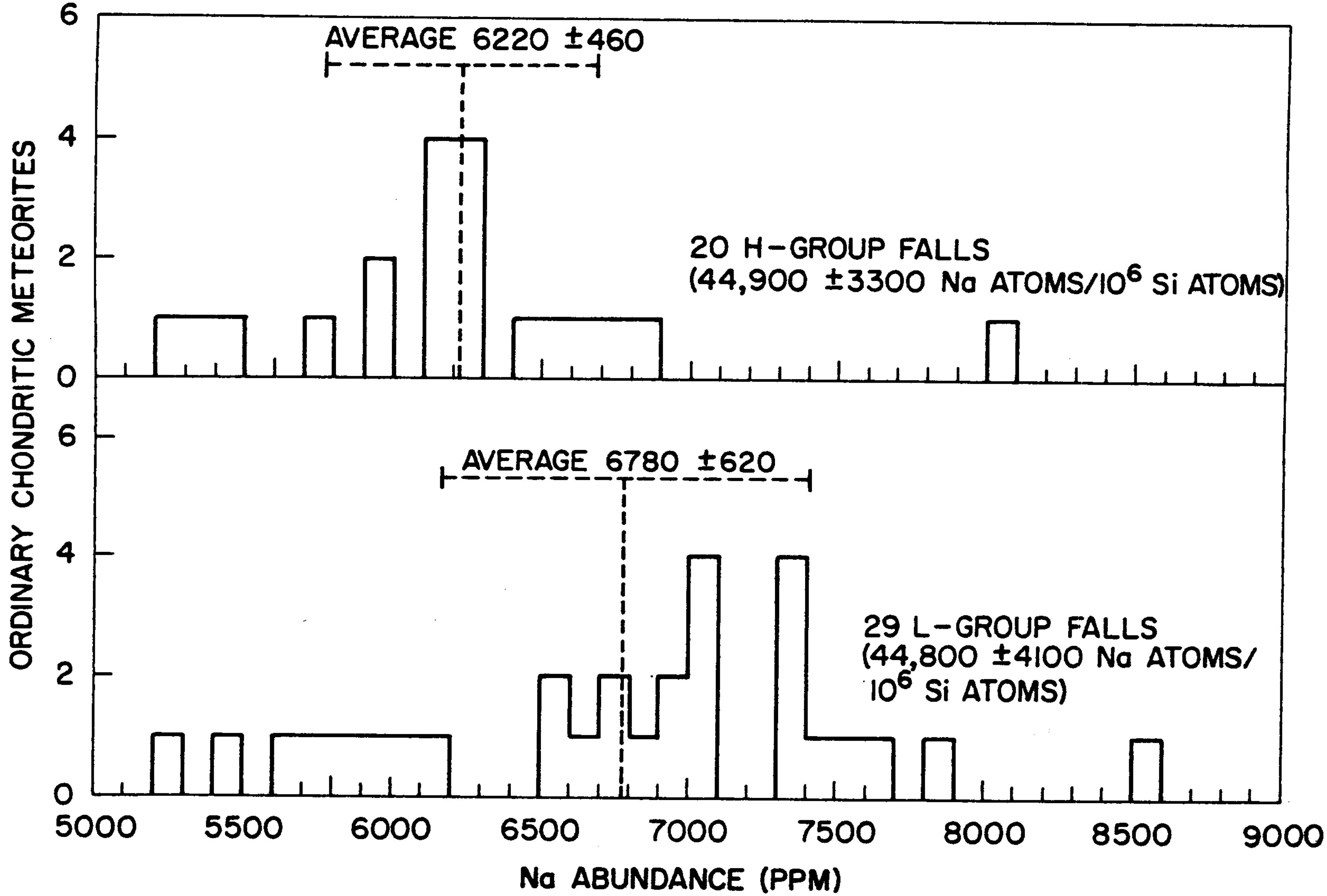

Fig. 1--Frequency distribution of Na in 20 H-group and 29 L-group ordinary chondrites (falls); typical error per chondrite = ±3%

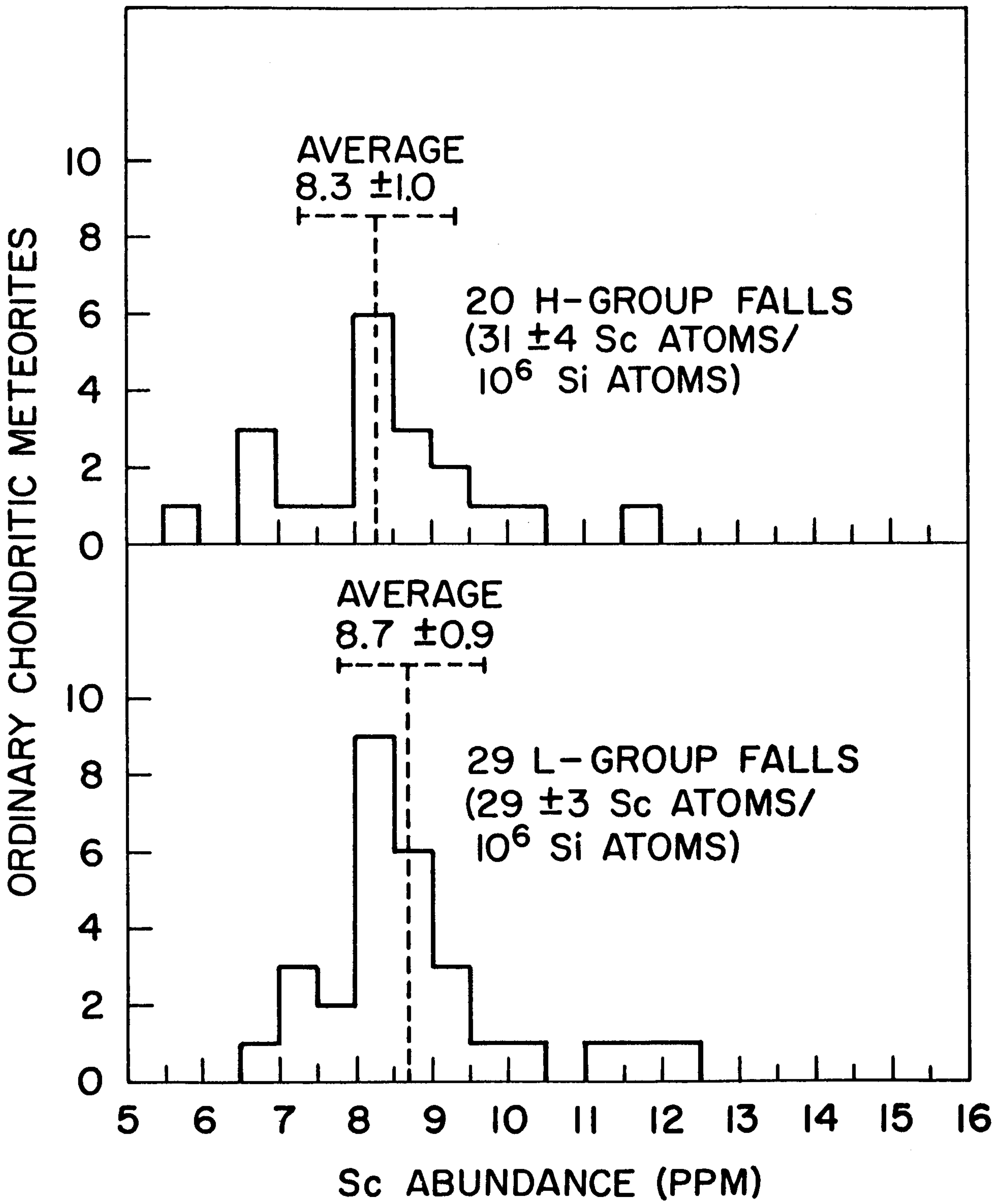

Fig. 2--Frequency distribution of Sc in 20 H-group (falls) and 29 L-group ordinary chondrites (falls); typical error per chondrite = ±8%

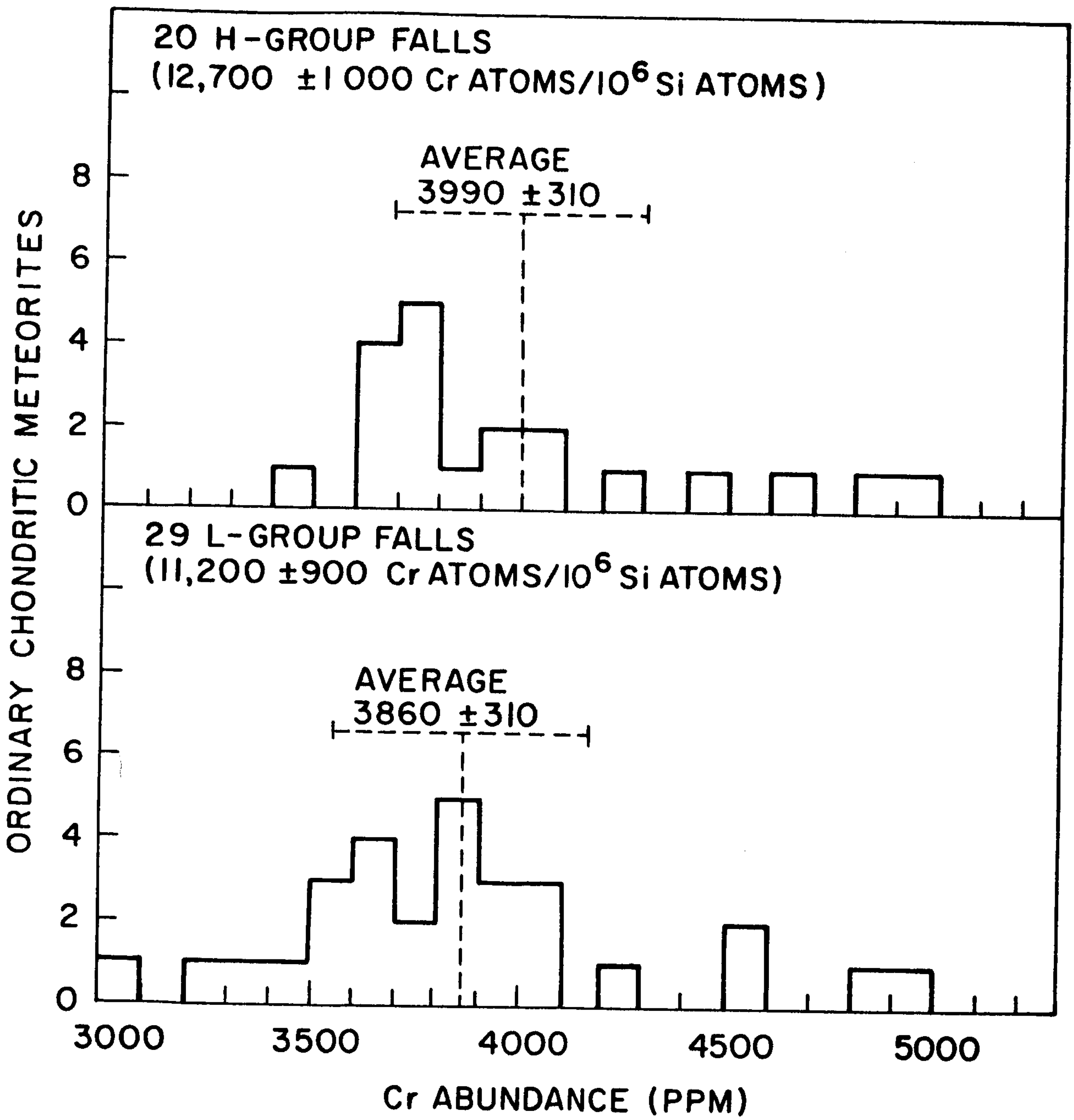

Fig. 3--Frequency distribution of Cr in 20 H-group and 29 L-group ordinary chondrites (falls); typical error per chondrite = ±2%

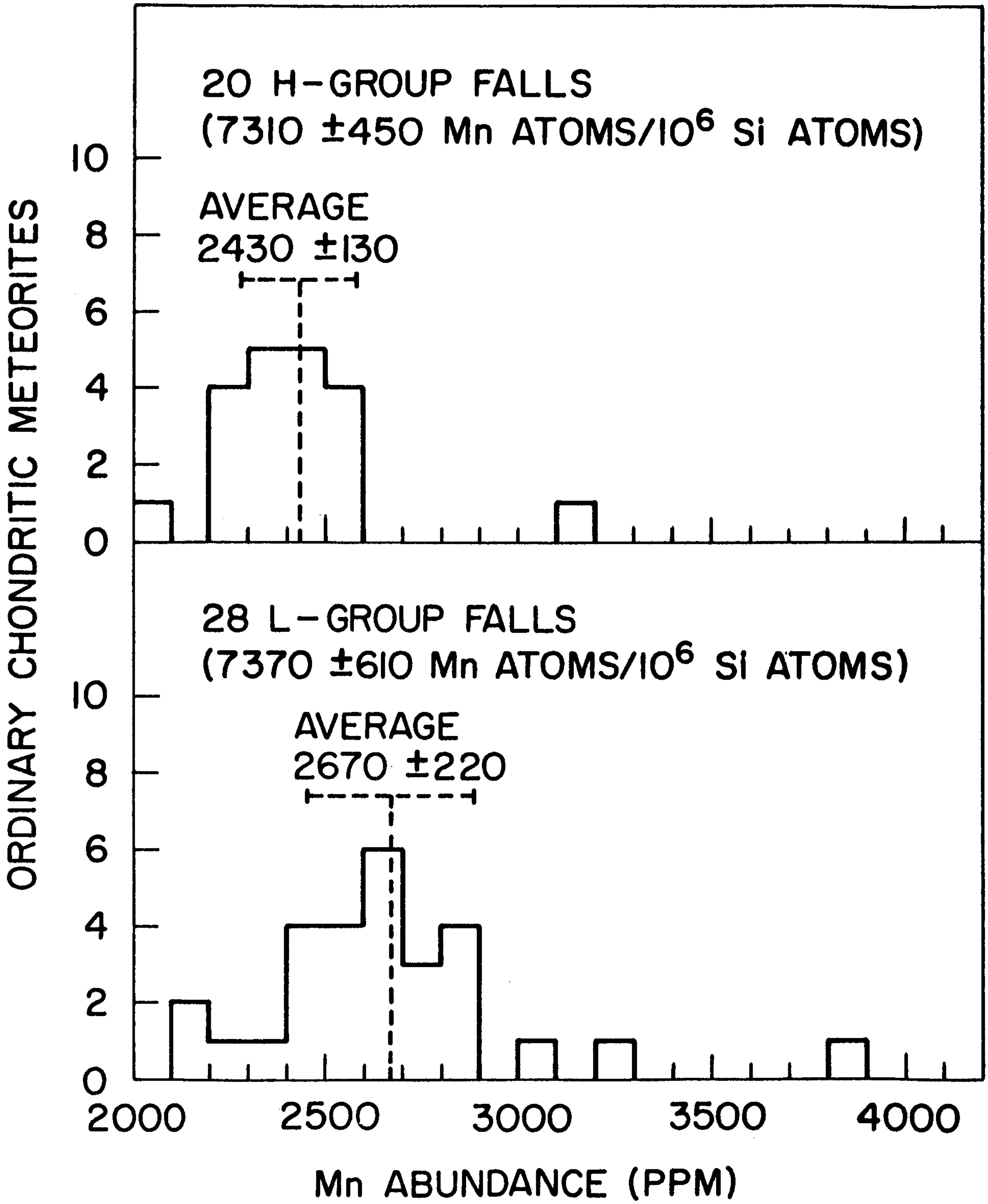

Fig. 4--Frequency distribution of Mn in 20 H-group and 28 L-group ordinary chondrites (falls); typical error per chondrite = ±2%

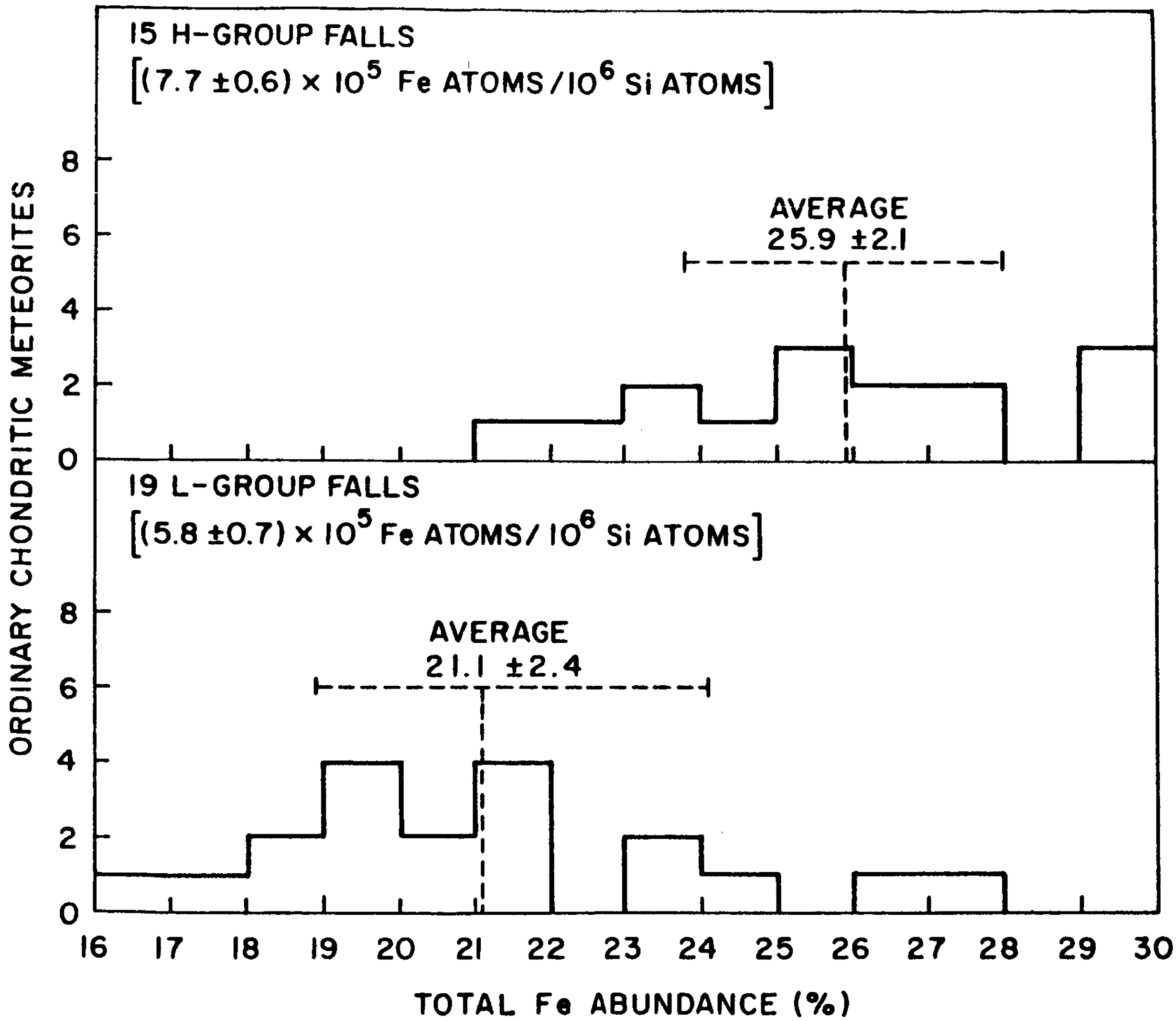

Fig. 5--Frequency distribution of total Fe in 15 H-group and 19 L-group ordinary chondrites (falls); typical error per chondrite = ±5%

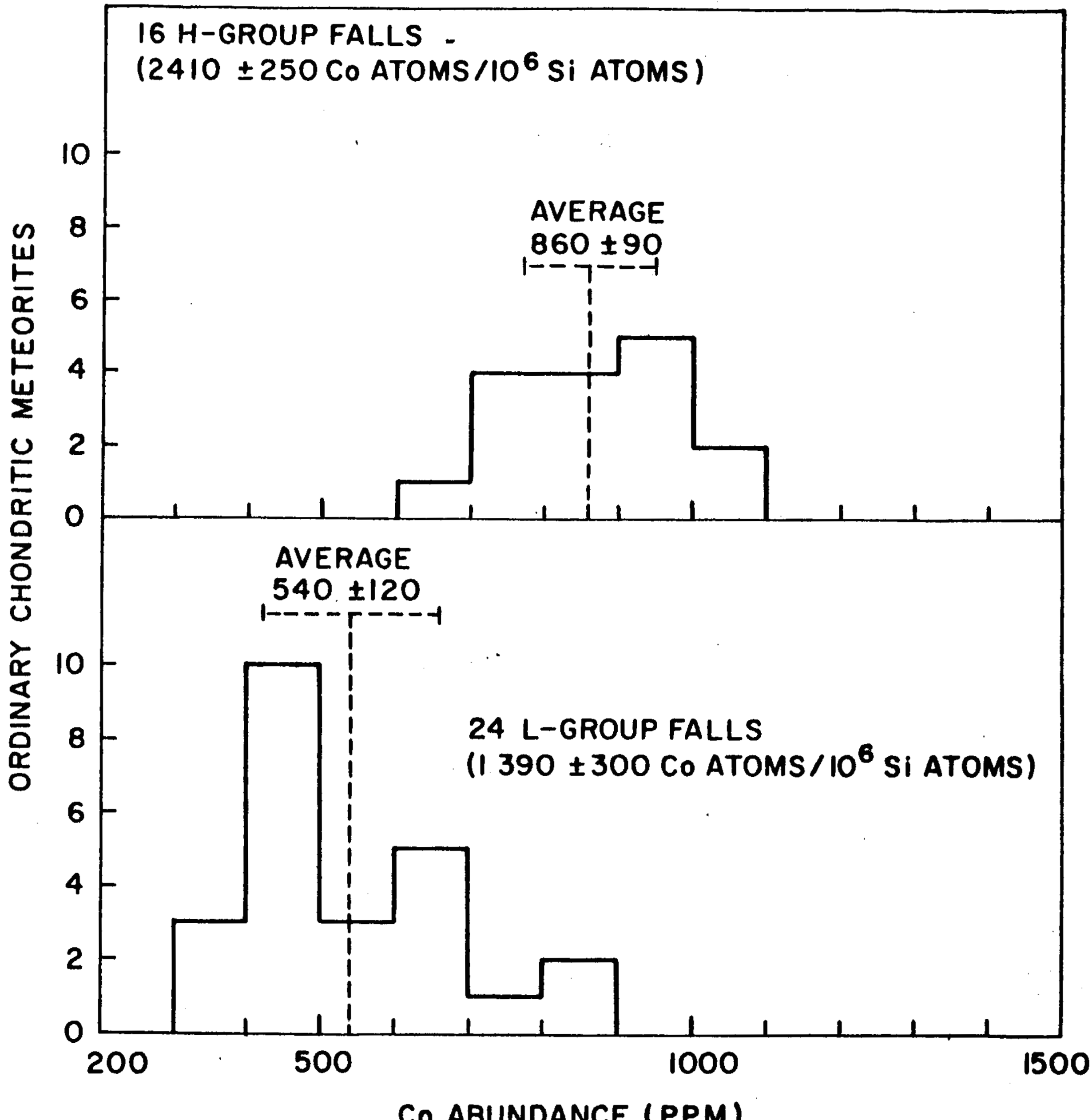

Fig. 6--Frequency distribution of Co in 16 H-group and 24 L-group ordinary chondrites (falls); typical error per chondrite = ±3%

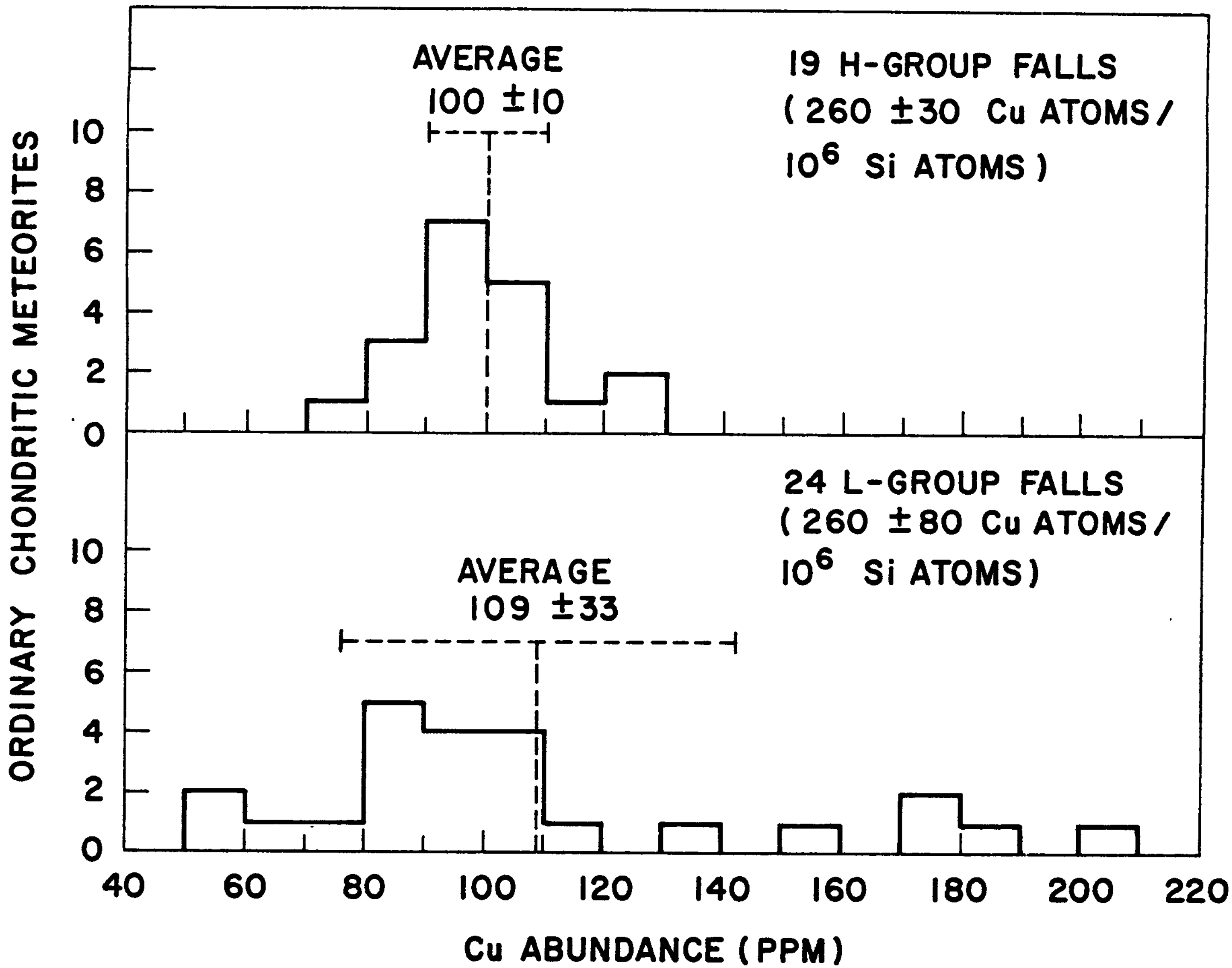

Fig. 7--Frequency distribution of Cu in 19 H-group and 24 L-group ordinary chondrites (falls); typical error per chondrite = ±15%

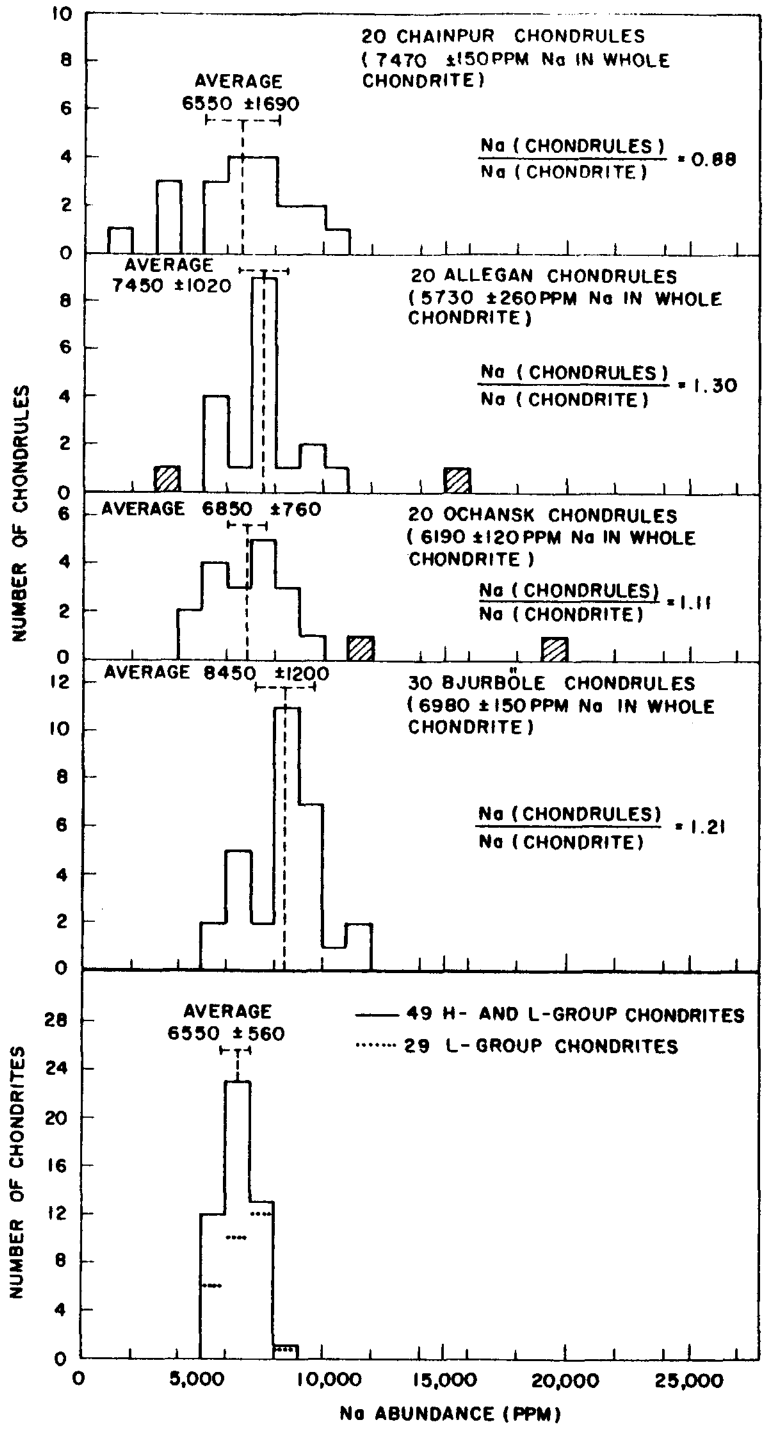

Fig. 8--Frequency distribution of Na in 20 chondrules of Chainpur (Type III carbonaceous chondrite), 20 chondrules of Allegan and 20 chondrules of Ochansk (H-group chondrites), and 30 chondrules of Bjurböle (L-group chondrite). Shaded values not included in averages. Typical error per chondrule = ±2%.

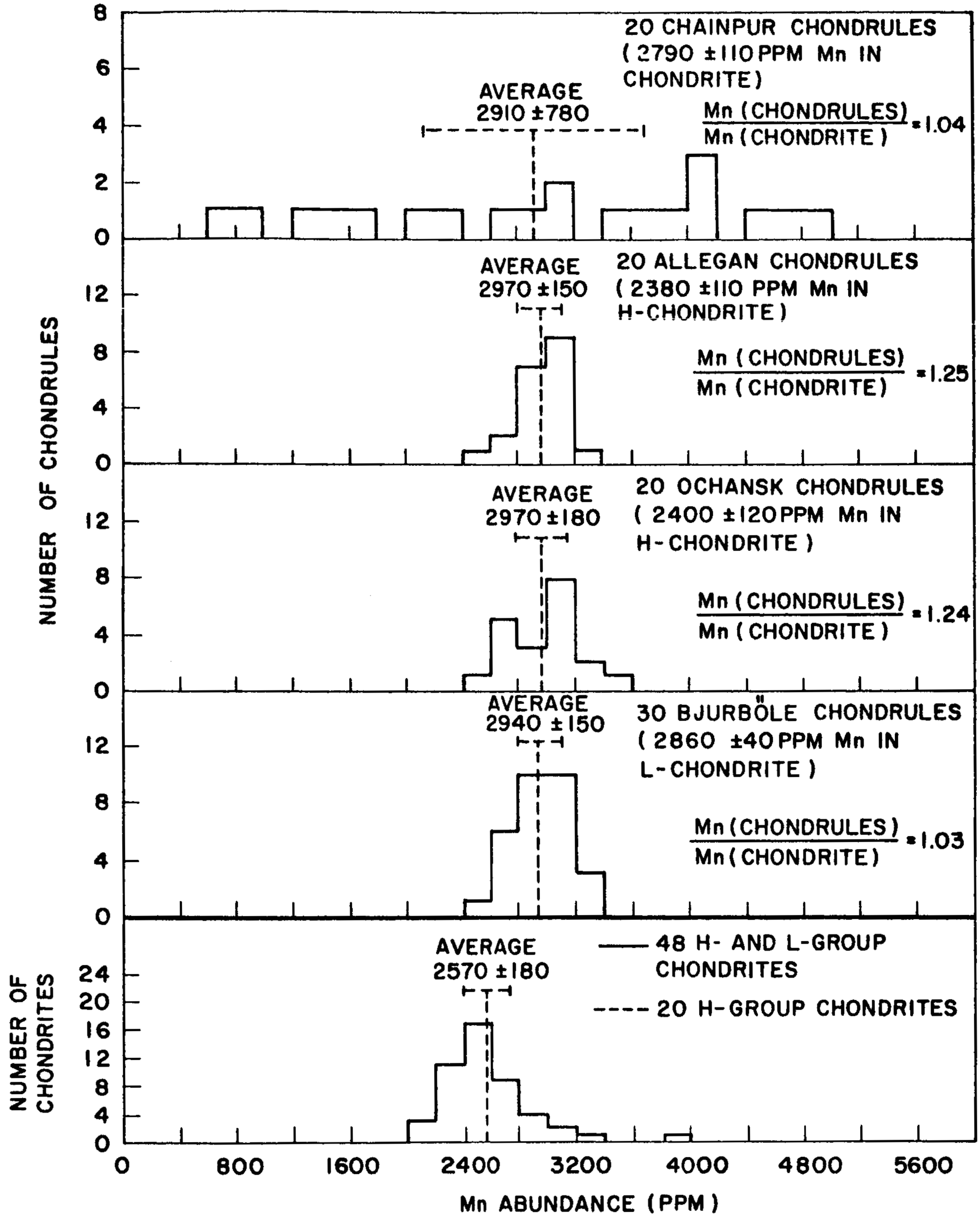

Fig. 9--Frequency distribution of Mn in 20 chondrules of Chainpur (Type III carbonaceous chondrite), 20 chondrules of Allegan and 20 chondrules of Ochansk (H-group chondrites) and 30 chondrules of Bjurböle (L-group chondrite); typical error per chondrule = ±2%

The agreement of the present Na value for Murray with the Na value obtained by Edwards and Urey for a different specimen of Murray, definitely establishes a low Na content for this Type II carbonaceous chondrite. This certainly indicates a history for Murray which is somewhat different from that of the other Type II carbonaceous chondrites.

In the Type III carbonaceous chondrites, the Na content in Chainpur is ~2 times the average Na content in 4 other chondrites of this type. For both Chainpur and Murray, none of the abundances of the other analyzed elements--Sc, Cr, Mn, Fe, Co, and Cu--is very different from the average abundances found in the respective categories of these two chondrites. Because of the general importance of establishing accurate abundance values for carbonaceous chondrites, larger numbers and quantities of these meteorites will be subjected to future INAA.

With the exception of Kapoeta, the 7 Ca-rich achondrites, Nakhla included, have a relatively constant Na atomic ratio of 17 ±2, as opposed to the fluctuations inferred from old data.

In ordinary chondrites, the Na concentrations are relatively homogeneous, at least for 0.3-g specimens (see the results for duplicate and triplicate analyses in Table 1). Large Na fluctuations have been found in three Ca-poor achondrites and also in two 0.4-g chunks of Ca-rich Bishopville. The $Na/10^6 Si$ atomic-ratio range in these three Ca-poor achondrites is 2 to 45. Actually, more Ca-poor achondrites, mesosiderites, and pallasites must be subjected to INAA in order to establish any distinct trends of Na abundances within any nonchondritic class of meteorites.

Concentrations of Na in terrestrial matter vary widely over the three principal classes--basalts, eclogites, and peridotites--but not too severely within each individual class. Again, more specimens must be analyzed to obtain meaningful correlations.

It is noted that the $Na/10^6 Si$ atomic ratio is essentially identical for the H- and L-group ordinary chondrites. Any physicochemical process responsible for segregation of the ordinary chondrites into these two groups[12] certainly has not affected the balance of Na and Si concentrations. As will be discussed below, abundances of Sc, Cr, Mn, and Cu are also essentially identical, within their respective mean deviations, for the H- and L-group chondrites. Differences in the Co contents in these two groups reflect to a first approximation the differences in the metallic Fe content in the groups. Only accurate abundance data will define the boundary conditions necessary for the interpretation of the origin of the H- and L-group chondrites. Unfortunately, much of the data now in the literature only helps to confuse the meteoritic theorist.

The Na data in Table 3 suggest a possible difference of ~20% in the Na contents for the 7 white L-group chondrites and the 8 intermediate and grey L-group chondrites. Additional chondritic analyses must be performed to clarify this point.

2. Sc. Abundances of Sc determined in this work (see Tables 1 and 2) by INAA agree well with those found by Schmitt, et al.,[2][3] who used radiochemical neutron activation analysis. The $Sc/10^6$ Si atomic ratios show considerable variation, ~25%, between the Type I and the Types II and III carbonaceous chondrites, while the atomic ratios in the H-, L-, and LL-group and enstatitic chondrites overlap within the large mean deviations. Because of the lack of Sc residence data in specific chondritic minerals, nothing may be inferred from the similarity of the $Sc/10^6$ Si atomic ratios in Type I carbonaceous and ordinary chondrites. The small mean deviation of $\sim\pm 12\%$ in the $Sc/10^6$ Si atomic ratios in Ca-rich achondrites underscores the similar past histories of the howardites and eucrites. The larger Sc atomic ratio for Nakhla indicates that this achondrite underwent a different fractionation[15] from the howardites and eucrites. Additional data must be obtained on other nonchondritic meteorites and terrestrial specimens in order to clearly establish any abundance trends. This statement also applies to the other six elements, Na, Cr, Mn, Fe, Co, and Cu.

3. Cr. The average Cr value of 3900 ppm obtained for 49 ordinary chondrites is 10% higher than Wiik's average of 3500 ppm.[16] With the exception of the Wiik[16] analyses, the preponderance of previous Cr analyses in meteorites are probably in error (see Table 1). The data for the carbonaceous chondrites do not indicate a severe fractionation of Cr with respect to Si. Furthermore, the Cr content in enstatitic chondrites is well below that in the carbonaceous chondrites. In contrast, abundances for the two elements Na and Mn in enstatitic chondrites agree well with those in Type II carbonaceous chondrites.

A comparison of the Cr and Mn abundances in 4 pallasites with those in ordinary chondrites reveals that in the pallasites the Cr content has been depleted by a factor of ~14 and the Mn content by a factor of ~1.2, or an order of magnitude less.

Keil[17] has examined 73 chondrites by planimetric integration of polished sections and reports average values of 2200 and 2700 ppm of chromite ($FeCr_2O_4$), which corresponds to 1030 and 1260 ppm Cr in H- and L-group chondrites, respectively. Since the total Cr abundances are 4000 ±300 and 3900 ±300 ppm in H- and L-group chondrites (see Table 2), the fractions of Cr as chromite in the H- and L-groups are 0.25 and 0.32, respectively. Consequently, the preponderance of Cr must reside in the pyroxenes, which is certainly consistent with the very low Cr abundances found in the olivine pallasites.

Any comprehensive meteoritic model will become valid only after satisfying accurate abundances which have been secured for the various meteoritic classifications. Furthermore, laboratory studies on the distribution of these and other elements in various meteoritic minerals as a function of temperature would be exceedingly helpful in deriving the histories of and relationships among meteorites.

4. Mn. From the Mn abundances given in Tables 1, 2, and 3, the following observations may be made. Previous Mn abundances obtained by Moore and Brown(18) (through spectrographic analysis) of 2530 ±300 ppm for 17 H-group falls and 2700 ±220 ppm for 20 L-group falls agree well with the INAA abundances of this work of 2430 ±130 and 2670 ±220 ppm for the 20 H-group falls and 29 L-group falls, respectively. As was observed for Na, there definitely is a decreasing $Mn/10^6$ Si atomic ratio in the three types of carbonaceous chondrites--8.8 ±0.4, 6.8 ±0.4, and 5.6 ±0.3 ppm in Types I, II, and III, respectively. The fractionation of Mn and Na with respect to Si must be accounted for if these types of carbonaceous chondrites are interrelated.(11) No differences were found within the various subclasses of chondrites for Mn abundances in both H- and L-group chondrites (see Table 3).

Engel and Engel(19) have correlated decreasing Mn concentrations in hornblendes and pyroxenes with increasing degrees of metamorphism. It does appear that no Mn transport has occurred within the designated chondritic subclasses, some of which may be related by differing degrees of metamorphism. Choice of this criterion is rather dangerous, especially since Mn content has not been accurately established in the various chondritic minerals.

For 5 Ca-rich achondrites, the $Mn/10^6$ Si atomic ratios are similar to those for Type I carbonaceous chondrites, whereas the Na and Cr ratios are smaller by a factor of ~3. The similarity of the mean deviations of the 4 elements Na, Sc, Cr, and Mn in the 5 Ca-rich achondrites suggests a very similar history of formation.

5. Fe. Total Fe concentrations of this work (see Table 1) agree well with other total Fe values. Values of Fe calculated via the 0.19-Mev γ peak of 45-d Fe^{59} during the previous quarter(8) have been excluded from this report. Where the values of this work are low, loss of metallic Fe incurred during preparation of the specimens may have been responsible owing to settling out of metallic Fe-Ni chunks. (Previous total Fe values in the literature are probably reliable to ±10%.)

6. Co. Analyses of 40 ordinary chondrites have confirmed the previous finding(8) that the Co content in ordinary chondrites may be associated with the metallic Fe content of these meteorites. To a first approximation, the

chondritic content of Co is not proportional to the metallic Fe content in the H-, L-, and LL-groups. It is planned to determine the exact relationship by measuring the metallic Fe content by a magnetic balance technique. Furthermore, Ni abundance will be ascertained by photoneutron activation. The accurate abundances of the elemental triad Fe, Co, and Ni should help to clarify Prior's rule. See Ref. 8 for a previous discussion of Co abundances.

7. Cu. The average Cu in 43 ordinary chondrites is 105 ±23 ppm, or 260 ±60 Cu atoms/10^6 Si atoms, which is 2.6 times larger than the corresponding solar value.[20] For two Type I carbonaceous chondrites, Orgueil and Ivuna, the Cu/10^6Si atomic abundances are identical at 490, which is 4.9 times the corresponding solar value. On the other hand, the theoretical Cu value by Clayton and Fowler[21] is 316, which is 1.2 and 0.7 times greater than the observed abundances in ordinary chondrites and Type I carbonaceous chondrites, respectively. Furthermore, from Table 1, the Cu abundance in enstatitic chondrites lies between Cu abundances in ordinary and Type I carbonaceous chondrites. Obviously, Cu abundances must be determined in more carbonaceous chondrites, nonchondritic meteorites, and terrestrial matter. See Ref. 8 for more details on Cu abundances.

COMMENTS ON ABUNDANCES IN CARBONACEOUS CHONDRITES

Abundances of Na, Sc, Cr, Mn, Fe, Co, and Cu have been determined in 3 Type I carbonaceous chondrites: Orgueil, Ivuna (in duplicate), and Alais. Only a small quantity from Alais was available; therefore, values for Alais have been excluded from the average (see Table 1). The mean deviation of the abundances of Na, Sc, Cr, Mn, Fe, Co, and Cu in Orgueil and Ivuna is ±5%. Since the abundances of the macroelements determined by Wiik,[16] the abundances of the 14 REE and Y (e.g., La = 0.19 ±0.01 ppm) determined by Schmitt, et al.,[2][3] and the abundance of Cd (1.0 ±0.1 ppm) determined by Schmitt, et al.,[22] are very similar for Orgueil and Ivuna, these two carbonaceous chondrites very probably had identical chemical histories. The importance of Type I carbonaceous chondrites has been discussed by Nagy, et al.(see Ref. 23 for further references).

Rowe, et al.,[24] have recently confirmed the K abundances found by Edwards and Urey[14] in 2 carbonaceous chondrites, Mighei and Felix. However, their K content for Murray[24] was higher than that found by Edwards and Urey. A comparison of the Na abundances of this work (see Table 1) with the K abundances of others[14][24] reveals that the Na/K ratio of ~12 in Type II Mighei and Type III Felix is 1.5 times the average Na/K ratio of ~8 in ordinary chondrites. More K abundances in carbonaceous chondrites are required to aid in interpretation of the data on the alkali elemental abundances.

REMARKS ON INDIVIDUAL METEORITES WITH "ABNORMAL" ABUNDANCES

Chainpur

Abundances of Na and Mn in Chainpur, a Type III carbonaceous chondrite, are 4 times greater than the mean (or even standard) deviation of the other 5 Type III chondrites. Mineralogical studies[4] of Chainpur have emphasized the heterogeneity of this chondrite.

Fayetteville

High concentrations of Fe and Co found in Fayetteville suggest a very high metallic content for the particular 0.11-g chunk of the meteorite analyzed. In fact, the oxyphilic elements Na, Sc, Cr, and Mn have been depleted uniformly by ~30%.

Kapoeta

Although Na and Sc values have been included in the averages for the Ca-rich achondrites, the abundances of these two elements are definitely lower than those observed for the 5 eucritic and howarditic achondrites. The Cr content, high by a factor of 2, in Kapoeta may reflect a higher pyroxene content in Kapoeta than in the other 5 achondrites.

The fact that the Co abundances are larger (by about an order of magnitude) in Kapoeta, as well as in Petersburg and Nakhla, than in 4 other Ca-rich achondrites may be attributed to the presence of trace quantities of metallic iron.

Murray

Of the 4 Type II carbonaceous chondrites subjected to INAA, only Murray has a low Na abundance. This value confirms that of Edwards and Urey,[14] who analyzed a different specimen of Murray. Abundances of the other 5 elements, Sc, Cr, Mn, Fe, and Co, in Murray are comparable to corresponding abundances in the three other Type II carbonaceous chondrites. Abundances of Na should be determined in different Murray stones in order to check the uniquenessof the low Na values in Murray relative to other Type II carbonaceous chondrites.

Nakhla

The high Sc value of 53 ppm in Nakhla corroborates the Sc values of 54 ppm obtained by Schmitt and Smith,[15] who used RNAA, and 49 ppm obtained by Greenland,[25] who used emission spectroscopy. Nakhlitic achondrites have undergone different chemical processes from the other Ca-rich achondrites. This is evidenced by the fractionation of the 14 REE.[15]

Pantar-II

No significant differences were found in the abundances of the elements Sc, Cr, Fe, and Co in duplicate analyses of the dark and light phases of the Pantar-II chondrites. (Also, no differences were observed during the previous quarter[8] for abundances of the elements Na, Mn, and Cu in the light and dark phases of Pantar-II.) Suess, Wänke, and Wlotzka[26] have discussed the significance of gas and certain elemental enrichments in the dark phases of particular chondrites.

Phillips County

Very high Co contents in this pallasite certainly reflect a large metallic phase in the analyzed specimen. Mineralogical studies should help to clarify the fact that Cr abundances are high and Mn abundances are low in this pallasite relative to corresponding abundances in other pallasites.

Pine River

This meteorite is actually an octahedrite "find" with many silicate inclusions. The analyzed silicate pieces have abundances of Na, Sc, Fe, Co, and Cu which are similar to those in H- and L-group chondrites. However, Cr and Mn abundances in Pine River are ~0.3 and ~0.5 times less, respectively, than corresponding abundances in either H- or L-group chondrites. From the summarized data of Table 2, it is noted that low values of Sc and Cr are found in olivine pallasites along with ~25% depletion of Mn. The data suggest an increased percentage of olivine (with decreased Cr and Mn) in the Pine River inclusions. The near-normal Na and Sc abundances found for Pine River would be satisfied by an appreciable Sc residence in plagioclase as well as in pyroxenes. Obviously, mineralogical evidence is needed to settle this point. The above suggestions rest upon the assumption that pallasites and mesosiderites have been derived from matter similar to chondrites in composition.

HOMOGENEITY OF CHONDRITES

The accurate abundances of the 7 elements Na, Sc, Cr, Mn, Fe, Co, and Cu (obtained by INAA techniques) which are given in Table 1 and averaged and summarized in Table 2 underscore the fact that the concentrations of most elements, whether in the ppm range or percentile range, are very constant, i.e., to ~±10%, within the various chondritic categories. Craig[27] has recently compiled all existing literature values of chondritic abundances (as of 6 months ago) and has found large variations, ~±30% for the mean deviations of the macroelemental concentrations of Al, Ca, Na, K, Cr, Mn, Ti, P, S, Ni, and Co. Statistically, in many cases, the averages of many old determinations nearly equaled the averages obtained in this work; however, the variations or mean deviations of these old analyses, some of which were considered superior analyses, were very large, say ~30%.

The small variations in abundances obtained in chondrites for elements with such diverse chemical properties as the alkali element Na, the siderphilic element Co, and the lithophilic and sometimes chalcophilic elements Mn and Cr certainly impose very stringent boundary values on any meteoritic parent model(s).

The authors[22] are well aware of the large variations found in chondrites for chalcophilic elements, such as Cd, Bi, Tl, etc. However, for most of these elements, the data are rather sparce and allow limited interpretation.

RESULTS AND DISCUSSION FOR ABUNDANCES OF Na, Sc, Cr, Mn, Fe, Co, AND Cu IN 90 INDIVIDUAL CHONDRULES

Tables 4, 5, 6, and 7 give the abundances of Na, Sc, Cr, Mn, Fe, Co, and Cu determined in individual chondrules from four chondrites: Allegan and Ochansk (two H-group chondrites), Bjurböle (an L-group chondrite), and Chainpur (a Type III carbonaceous chondrite). Average abundances given in Tables 4 through 7 for chondrules have been compiled in Table 8. Missing values for several elements are at present in the stage of data reduction. Histograms of Na and Mn distributions are given in Figs. 8 and 9. From these data, the following observations may be made:

1. The most striking result is the uniform Mn abundance of 2960 ±160 ppm in 70 individual chondrules from 3 ordinary chondrites (see Table 8 and Fig. 9).

2. In 20 chondrules from a Type III carbonaceous chondrite, Chainpur, the Mn abundance varied randomly from 600 to 4600 ppm. However, the average abundance of 2910 ±790 agrees with the average of 2960 ±150 found in all 70 chondrules (see Table 8 and Fig. 9). Mn abundances in the chondrules from Allegan and Ochansk are greater by 25% than those found in the whole-rock-type chondrites (chondrules are by definition included in analyses of whole-rock types), while the average Mn abundances in Bjurböle are ~3% greater in chondrules.

3. Abundances of Na in 70 individual chondrules from 3 ordinary chondrites are from 11% to 30% more abundant than Na abundances in whole-rock-type chondritic matrices. For Chainpur, the average Na abundances in 20 chondrules were ~12% less than that in the matrix. Mean deviations of the average Na abundances in chondrules from the 4 chondrites ranged from ±11% to ±26% as compared with a range for Mn of ±5% to ±27%. For both Na and Mn, the largest mean deviations were for Chainpur chondrules. The high variability (large mean deviations) in Na and Mn abundances in Chainpur chondrules as compared with those in other chondrules of this work agrees with the findings of Keil and Fredriksson[5] and Mason.[28] They found by microprobe techniques[4] that the chondrules in Chainpur have widely varying olivines and pyroxenes in contrast to the relatively constant composition of olivines in Bjurböle chondrules.

4. Although the data are incomplete, abundances of Sc fluctuate widely in all chondrules from the 4 chondrites: in Allegan, 4.1 to 26 ppm as compared with 8.1 ±0.6 in the matrix; in Ochansk, 9.1 to 24.2 ppm as

compared with 8.9 ±0.5 ppm in the matrix; in Bjurböle, 4.5 to 13.5 ppm as compared with 8.6 +0.5 ppm in the matrix; and in Chainpur, 5.6 to 21.6 ppm, averaging 9.8 ±2.6 ppm in 20 chondrules, as compared with 10.4 ±0.5 in the matrix. For Chainpur, the average Sc content in chondrules overlaps that present in the whole-rock chondrites.

5. Incomplete Cr data show a variation in $Cr/10^6$ Si ratios of ~3 in some chondrule groups. For Chainpur chondrules, Cr is the only element that does not fluctuate severely, having a ±10% mean deviation for 20 chondrules. For this chondrite the ratio of Cr in chondrules to Cr in the chondrite equals that found for Mn.

6. Total Fe concentrations (from incomplete data) vary widely from chondrule to chondrule: e.g., in Allegan, 5.0% to 15.2% (29.8% ±1.9% in the matrix); in Ochansk, 1.6% to 13.0% (28.4% ±1.0% in the matrix); in Bjurböle, 5.8% to 20.8% (21.6% ±0.8% in the matrix); and in Chainpur, 3.0% to 22.9% (16.7% ±0.5% in the matrix).

7. Incomplete abundances of Co range widely and are usually well below the concentrations present in the whole-rock matrix: e.g., in Allegan, 3 to 131 ppm (900 ±110 ppm in the matrix); in Ochansk, <7 to 165 ppm (710 ±15 ppm in the matrix); in Bjurböle, 1 to 206 ppm (520 ±20 ppm in the matrix); and in Chainpur, 12 to 960 ppm (490 ±10 ppm in the matrix).

In Chainpur, the high Co contents are found in magnetic chondrules, which are apparently rich in metal phase. In Ochansk, too, the high Co contents in magnetic chondrules prevail. As for the chondrites, it is planned to quantitate the metal phases in chondrules with a magnetic balance. This information should yield any existing Co-Fe correlation.

8. Incomplete Cu abundances show fluctuating values: e.g., in Allegan, 3 to 53 ppm (105 ±20 ppm in the matrix); in Ochansk, 29 to 109 ppm (93 ±8 ppm in the matrix); in Bjurböle, <13 to 186 ppm (176 ±16 ppm in the matrix); and in Chainpur, 0 to 172 ppm (62 ±9 ppm in the matrix). Magnetic chondrules in Chainpur apparently have as much Cu, 83 ±33 ppm (56 to 172 ppm), as the whole-rock matrix. On the other hand, many of the nonmagnetic Chainpur chondrules have no observable Cu.

9. For the Ochansk chondrules, the Na concentrations increase with decreasing chondrule mass (by ~13% for chondrules differing in mass by a factor of 10), which suggests some surface phenomenon. For Ochansk, the large magnetic chondrules have Na contents which are lower by ~23% (in mass) than Na contents in nonmagnetic chondrules. It is noted that the total Fe contents in these two chondrule groups are more or less comparable to a first approximation, which eliminates the theory of a simple displacement of silicate phases by metallic phases.

In Bjurböle, the average ratio of Na concentrations for chondrules of 1.0- to 1.6-mg mass to Na concentrations for chondrules of 0.5- to 1.0-mg mass is 1.12.

No chondrule mass effect has been observed for Mn for the 4 chondrites.

CHONDRULE ABUNDANCE SUMMARY

Although the abundances of the 7 elements Na, Sc, Cr, Mn, Fe, Co, and Cu in these 90 chondrules from 4 meteorites have yielded an enormous amount of data, the authors and collaborators have deliberately refrained from speculating (sophisticated word for guessing) on chondrule origin. Only after chondrules from many different chondrites have been subjected to INAA and other techniques and the abundances of many other chemical elements have been ascertained can meaningful theories of chondrule origin be made.

ACKNOWLEDGMENTS

The authors acknowledge the assistance of R. A. Cox, J. R. Huddlestone, and Mrs. Virginia Frankum (of the University of California at San Diego) for help in preparing samples and counting the irradiated specimens.

Table 1

ABUNDANCES OF Na, Sc, Cr, Mn, Fe, Co, AND Cu IN METEORITIC AND TERRESTRIAL MATTER BY INAA[a]

	Type of Meteorite[b]	Meteorite[c]	Mass (g)	Abundances: Na (ppm)	Na atoms/10^6 Si atoms	Sc (ppm)	Sc atoms/10^6 Si atoms	Cr (ppm)	Cr atoms/10^6 Si atoms
(1)	Carbonaceous Type I Fa, Ck	Orgueil	0.189	5180 ±100 (5500)$_{EU}$	60,000	5.2 ±0.4 (5.3 ±0.3)$_S$ (6.3)$_G$	31	2720 ±30 (2500)$_W$ (2220)$_G$ (2600)$_N$	14,200
(2)		Alais	0.0295	4740 ±250		8.1 ±0.6		2010 ±40 (7000)$_{Cr}$	
(3)		Ivuna, A	0.392	5560 ±120 } 5490 ±70 (5600)$_{EU}$	63,000	4.8 ±0.3 } 5.0 ±0.2	32	2400 ±50 } 2380 ±30	12,100
(4)		Ivuna, B	0.431	5420 ±120		5.2 ±0.3 } (5.9 ±0.3)$_S$		2350 ±50	
(5)	Carbonaceous Type II	Boriskino	0.280	3630 (7900)$_W$	35,500	8.8 (8.1)$_S$	44	3050 (2050)$_W$	13,200
(6)	Fa, Ck	Mighei	0.063	4360 (4700)$_{EU}$	40,900	8.6 (8.6)$_S$	41	2940 (2460)$_W$	12,200
(7)		Murray	0.201	1690 (1600)$_{EU}$ (out)	15,300 (out)	10.6 (11.3)$_S$	49	3170 (3010)$_W$	12,700
(8)		Santa Cruz	0.052	4780 ±150 (3700)$_W$	42,500	9.5 ±0.8	43	3390 ±70 (2700)$_W$	13,300
		Average[g]		4260 ±420	39,600 ±2800	9.4 ±0.9	44 ±2	3140 ±140	12,800 ±400
(9)	Carbonaceous Type III Fa, Cc	Chainpur	0.315	7470 ±150 (out)		10.4 ±0.5		3450 ±40	
(10)	Fa, Cck	Felix	0.179	4550 (4400)$_{EU}$ (4600)$_{Cr}$	35,400	12.3 (9.7)$_S$	49	3660 (3010)$_W$ (5500)$_{Cr}$	12,500
(11)	Fa, Cs	Groznaia	0.280	2700	21,000	9.4 (10.1)$_S$	37	3340	11,400
(12)	Fa, Cg	Karoonda	0.0839	3420 ±100		11.6 ±0.7 (14.0)$_G$		3750 ±60 (2730)$_G$	
(13)	Fa, Ck	Mokoia	0.257	2970 (3800)$_{EU}$	23,200	12.3 (10.4)$_S$ (7.9)$_G$	49	3500 (3560)$_W$ (2280)$_G$	12,100
(14)	Fa, Cc	Warrenton	0.169	4390 ±90 (5100)$_{UC}$ (1700)$_{Cr}$	32,600	8.8 ±0.7 (8.5)$_G$	34	2160 ±60 (out) (4000)$_{UC}$ (3010)$_G$ (400)$_{Cr}$	7150 (out)
		Average[g]		3600 ±690	28,000 ±6000	10.5 ±0.8	42 ±7	3540 ±130	12,000 ±400
(15)	Ordinary chondritic, H group Fa, Cia	Agen	0.191	6430 ±120		8.3 ±0.6		3690 ±40 (1920)$_{UC}$	
(16)	Fa, Cga	Alessandria	0.254	5890 ±100		8.0 ±0.6		4000 ±40 (5800)$_{Cr}$	
(17)	Fa, Cc	Allegan, A	0.637	6020 ±120 } 5730 ±2.60	45,000	9.0 ±0.7 } 8.1 ±0.6	34	3410 ±70 } 3640 ±150	11,300
(18)		Allegan, B	0.462	5350 ±110 } (4910)$_{UC}$	40,000	7.5 ±0.6 } (5.0)$_G$	28	3750 ±40 } (3600)$_{UC}$	12,100
(19)		Allegan, C	0.634	5830 ±120 } (7400)$_{EU}$	43,600	7.7 ±0.6	29	3750 ±40 } (2070)$_G$	12,400
(20)	Fa, Cck	Ambapur Nagla	0.100	6840 ±140		6.7 ±0.6		4060 ±40	
(21)	Fa, Cg	Archie	0.297	6110 ±120		6.8 ±0.5		3640 ±40	
(22)	Fa, Cga	Barbotan	0.162	6280 ±120		8.2 ±0.6		4960 ±50	
(23)	Fa, Cg	Beardsley, A	0.238	5770 ±120 } 5380 ±380		8.6 ±0.7 } 8.0 ±0.6		3830 ±60 3710 ±120	11,500
(24)		Beardsley, B	0.330	5000 } (6600)$_{EU}$		7.4 } (9.2)$_{BPH}$		3600 (2300)$_{BPH}$	
(25)	Fa, Cck	Beaver Creek	0.362	5980 ±120 (6000)$_{UC}$	41,100	6.7 ±0.7	24	3780 ±40 (2880)$_{UC}$	
(26)	Fa, Cca	Bielokrynitschie	0.068	6710 ±140		7.3 ±0.7		4650 ±50	
(27)	Fa, Cs	Bishunpur	0.096	8070 ±160		5.9 ±0.6		3750 ±50	
(28)	Fa, Cgb	Castalia	0.402	6500 ±130 (4100)$_{Cr}$		8.8 ±0.9		4430 ±40	
(29)	Fa, Cia	Colby	0.086	5440 ±120 (7300)$_{EU}$ (8000)$_{Cr}$		8.9 ±0.7		3790 ±40 (3400)$_{Cr}$	
(30)	Fi, Ca	Cortez	0.059	7260 ±140		7.6 ±0.8		4500 ±80	
(31)	Fa	Ehole	0.456	6150 ±120		8.6 ±0.5		4800 ±50	
(32)	Fa	Fayetteville	0.107	4530 ±90 (out)		5.0 ±0.8 (out)		2520 ±50 (out)	
(33)	Fa, Cg	Kilbourn	0.472	6230 ±120		8.1 ±0.8		3710 ±60	
(34)	Fa, Cg	Miller	0.133	5270 (6000)$_{MW}$	36,000	10.2 (7.8)$_S$	30	3470 (2200)$_{MW}$	10,500
(35)	Fa, Cga	Monroe	0.027	6200 ±120		10.3 ±1.3		3680 ±40	
(36)	Fa, Ccb	Ochansk, A	0.307	6190 ±120 (4900)$_W$	45,000	9.7 ±0.8	36	3870 ±70 } 3850 ±20	12,500
(37)		Ochansk, B	0.376	----		8.9 ±0.5	33	3840 ±40	12,400
(38)	Fa, Ca	Pantar II-dark, A	0.421	6250 ±120 } 6210 ±40		8.2 ±0.6 } 8.1 ±0.1		4070 ±40 } 3990 ±80	
(39)		Pantar II-dark, B	0.420	6180 ±120		8.0 ±0.7		3920 ±40	
(40)		Pantar II-light, A	0.294	6560 ±120 } 6320 ±230		7.2 ±0.6 } 7.1 ±0.2		4030 ±40 } 3980 ±50	
(41)		Pantar II-light, B	0.370	6090 ±120		6.9 ±0.6		3930 ±40	
(42)	Fi	Pine River (octahedrite silicate inclusion)	0.420	6080 ±120 (out)		10.1 ±0.5 (out)		1270 ±30 (out)	
(43)	Fa	Pultusk	0.340	6180 ±120 (11,000)$_{Cr}$		11.6 ±0.5		4220 ±40 (1400)$_{Cr}$	
(44)	Fa, Cgb	Ställdalen	0.174	6670 ±120 (6000)$_A$ (4600)$_{UC}$	48,600	9.8 ±0.7 (12)$_C$	37	3980 ±80 (4800)$_C$	12,800
		Average[h]		6220 ±460	44,900 ±3300	8.3 ±1.0	31 ±4	3990 ±310	12,700 ±1000
(45)	Ordinary chondritic, L group Fa, Cc	Albareto	0.366	7050 ±140 (9130)$_{UC}$ (12,200)$_{Cr}$	45,500	7.4 ±0.6	24	3810 ±40 (1900)$_{UC}$	10,900
(46)	Fa, Ci	Alfianello	0.115	8550 ±160 (6700)$_{Cr}$	58,500	8.3 ±0.6	29	3690 ±90 (2900)$_{Cr}$	11,200
(47)	Fi, A	Arcadia	0.155	6440 ±120		9.2 ±0.6		3670 ±70	
(48)	Fa, Cs	Atarra	0.136	7380 ±140		9.4 ±0.5		4020 ±40	
(49)	Fa, Cg	Atemajac	0.107	7050 ±140		8.5 ±0.6		3910 ±40	
(50)	Fa, Cgb	Athens	0.0140	6700 ±130 (8500)$_{Cr}$		9.6 ±1.3		4080 ±40	
(51)	Fa, Cc	Aussoun	0.352	6900 ±150 (4200 to 18,000)$_{Cr}$		7.8 ±0.6		3730 ±40 (6100)$_{Cr}$	
(52)	Fa	Aztec	0.099	7830 ±160		12.1 ±0.6		3870 ±40	
(53)	Fi, Cs	Barratta	0.390	6160 ±120 (6900)$_{EU}$ (6000)$_{Cr}$		9.3 ±0.5 (7.6)$_G$		3500 ±70 (3020)$_G$	
(54)	Fa, Ci	Bath Furnace	0.476	6640 ±130		8.4 ±0.6		3890 ±40	
(55)	Fa, C	Baxter	0.377	7600 ±150		7.4 ±0.5		3480 ±40 } 3430 ±60	
(56)	Fa, C	Benton	0.062	5660 ±110		11.6 ±1.6		3370 ±40	

Table 1--continued

	Abundances							
	Mn (ppm)	Mn atoms/10^6 Si atoms	Fe^d (%)	Fe atoms/10^6 Si atoms ($\times 10^5$)	Co (ppm)	Co atoms/10^6 Si atoms	Cu^e (ppm)	Cu atoms/10^6 Si atoms
(1)	1870 ±90 $(1500)_W$ $(1810)_G$ $(1900)_N$	9000	18.6 ±0.6 $(18.5)_W$ $(25)_{Cr}$ $(18.5)_G$ $[0.0]_W$	8.8	520 ±20 $(500)_W$ $(532)_G$ $(400)_N$	2350	119 ±13 $(247)_G$ $(200)_N$	490
(2)	2120 ±80 $(16,000)_{Cr}$		14.4 ±0.8		550 ±20		290 ±50	
(3)	1760 ±30 } 1780 ±20 $(1800)_W$	8550	17.5 ±0.4 } 16.8 ±0.8 $(19.1)_W$ $[0.00]_W$	7.9	460 ±10 } 470 ±10	2110	111 ±8 } 118 ±7	490
(4)	1800 ±30		16.2 ±0.3		470 ±10		125 ±7	
(5)	1790 $(1200)_W$	7300	$(20.9)_W$ $(20.8)_{Cr}$ $[0.0]_W$		500 $(300)_W$	1900	----	
(6)	1570 $(1600)_W$	6150	$(21.3)_W$ $[0.00]_W$		550 $(600)_W$	1960	----	
(7)	1880 $(1600)_W$ (2600)	7130	$(21.3)_W$ $[0.00]_W$		460 $(600)_W$	1710	----	
(8)	1780 ±90 $(1500)_W$	6600	19.1 ±1.0 $(17.4)_W$ $[0.00]_W$	7.0	700 ±20 $(600)_W$	2430	152 ±30	490
	1750 ±100	6800 ±400	(20.2 ±1.4$)_W$		550 ±70	2000 ±200		
(9)	2790 ±110 (out)		16.7 ±0.5		490 ±10		62 ±9	
(10)	1650 $(1600)_W$ $(1600)_{MB}$ $(5300)_{Cr}$	5340	$(26.1)_W$ $(26.0)_{Cr}$ $[4.7]_W$		650 $(880)_{Cr}$ $(800)_W$	1970	----	
(11)	1900	6200			480	1460	----	
(12)	1480 ±80 $(1290)_G$		20.0 ±1.0 $(24.2)_G$ $(23.9)_{Cr-U}$		740 ±30 $(716)_G$		147 ±19	
(13)	1720 $(1500)_W$ $(1470)_G$	5630	$(22.6)_G$ $(24.1)_W$ $[0.00]_W$		620 $(554)_G$ $(600)_W$	1880	---- $(77)_G$	
(14)	1690 ±80 $(1600)_{UC}$	5280	25.1 ±1.0 $(26.2)_{UC}$ $(27.5)_{Cr}$ $[4.0]_{UC}$	7.7	680 ±20 $(800)_{UC}$	1990	144 ±15 $(103)_G$	390
							120 ±30	
	1690 ±100	5590 ±300	(22.4 ±3.2$)_{TP\ and\ W}$		610 ±80	1820 ±180		
(15)	2460 ±30		23.5 ±1.2		870 ±20		88 ±14	
(16)	2080 ±20		29.2 ±0.9 $(28.3)_{Cr}$		1090 ±20		92 ±10	
(17)	2220 ±60 } 2380 ±110 $(1400)_{UC}$ $(2220)_{MB}$ $(2210)_G$	6930	28.5 ±1.0 } 29.8 ±1.9 (30.9) $[21.1]_{UC}$ $(28.8)_G$	8.8	830 ±20 900 ±110	2420	75 ±10 } 105 ±20 $(80)_G$	200
(18)	2430 ±150	7580	28.3 ±1.4	8.7	1070 ±20 $(1500)_{UC}$	3120	111 ±10	300
(19)	2500 ±150	7800	32.7 ±1.1	10.2	800 ±20 $(908)_G$	2340	129 ±12	340
(20)	2550 ±50		25.1 ±1.0		1040 ±20		123 ±13	
(21)	2200 ±40		26.9 ±0.8		880 ±20		107 ±11	
(22)	2320 ±50		27.8 ±1.4		980 ±20		118 ±15	
(23)	2530 ±120 } $(2700)_{MB}$ 2440 ±90		24.3 ±0.9 } 23.8 ±0.6		880 ±30 } 810 ±70		95 ±13	260
(24)	2350		23.4		740		----	
(25)	2320 ±50 $(1630)_{UC}$	6670	27.5 ±0.8 $(27.0)_{UC}$ $[16.0]_{UC}$	7.8	840 ±20 $(800)_{UC}$	2250	105 ±11	
(26)	2580 ±50		22.6 ±1.2 (out) $[15.8]_K$		740 ±20 (out)		108 ±20	
(27)	2580 ±50		20.8 ±0.6 (out)		1120 ±30 (out)		95 ±20	
(28)	2380 ±50		22.5 ±1.2 $(24.5)_{Cr-U}$		780 ±20		86 ±9	
(29)	2220 ±60 $(2010)_{MB}$ $(3500)_{Cr}$		22.2 ±0.8 (out) $(17.4)_{Cr}$		800 ±20 (out) $(360)_{Cr}$		95 ±16	
(30)	3040 ±150		16.5 ±1.1		730 ±30		144 ±29	
(31)	2490 ±140		29.7 ±1.0		960 ±20		79 ±8	
(32)	1715 ±80 (out)		44.4 ±1.8 (out)		2100 ±60 (out)		158 ±17 (out)	
(33)	2340 ±50		25.1 ±0.8		760 ±20		105 ±8	
(34)	3190 $(2400)_{MW}$	9130			680 $(610)_{MW}$	1800	----	
(35)	2290 ±70 $(1800)_{Cr}$		30.1 ±1.5 (out) $(26.5)_{Cr}$ $(27.0)_{MW}$		1260 ±40 (out) $(4900)_{Cr}$		96 ±5	
(36)	2400 ±120 $(2000)_W$ $(2620)_{MB}$	7320	25.0 ±1.3 } 25.5 ±0.5 $(27.9)_W$ $[19.1]_W$ $(29)_{Cr}$	7.5	790 ±20 } 750 ±40	2240	93 ±8	250
(37)	----		26.0 ±0.8	7.8	710 ±20	2020	----	
(38)	2370 ±100 } 2570 ±200 $(1300)_C$ $(2330)_{MB}$		29.2 ±1.2 } 26.4 ±3.2		930 ±20 } 770 ±150		86 ±3 } 90 ±4 $(170)_C$	
(39)	2760 ±180		23.5 ±0.8		620 ±20		93 ±7	
(40)	2360 ±120 } 2550 ±190 $(1300)_C$		25.2 ±1.0 } 26.4 ±1.2		720 ±20 } 790 ±70		77 ±10 } 88 ±11 $(170)_C$	
(41)	2740 ±140		27.6 ±1.0		850 ±20		99 ±8	
(42)	1200 ±60 (out)		18.4 ±0.8 (out)		750 ±30 (out)		92 ±10 (out)	
(43)	2280 ±110 $(2250)_{MB}$ $(4200)_{Cr}$		21.6 ±0.6 $(22.4)_{Cr-U}$ $[16.6]_K$		800 ±20		90 ±9	
(44)	2430 ±120 $(1900)_{UC}$ $(1600)_C$	7410	24.3 ±1.0 $(29.1)_{UC}$ $(27.6)_A$ $[18.9]_{UC}$ $[16.9]_A$	7.3	900 ±30 $(1100)_C$ $(1700)_{UC}$	2560	124 ±20 $(170)_C$	330
	2430 ±150	7310 ±450	25.9 ±2.1 (15)	7.7 ±0.6	860 ±90 (16)	2410 ±250	100 ±10 (19)	260 ±30
(45)	1210 ±20 $(1090)_{UC}$ (out)	3270	19.8 ±0.6 $(20.2)_{UC}$ $(23.2)_{Cr-U}$ $[4.5]_{UC}$	5.3	490 ±20 $(1000)_{Cr}$	1230	80 ±8	190
(46)	2620 ±30 $(2800)_{MB}$ $(1000)_{Cr}$	7500	20.0 ±0.6 $(27)_{Cr-U}$ $[6.8]_K$	5.6	450 ±20 $(800)_{Cr}$	1200	86 ±16	210
(47)	2810 ±150		18.9 ±0.9		430 ±20		78 ±16	
(48)	2670 ±60		19.6 ±0.6		340 ±20		80 ±16	
(49)	2690 ±60		16.3 ±0.6		490 ±20		102 ±10	
(50)	2560 ±50		14.9 ±1.7 (out) $(30.2)_{Cr}$		390 ±30 (out)		58 ±48	
(51)	2620 ±50 $(2600)_{Cr}$		21.5 ±0.8 $(22.9)_{UC}$ $(24.7)_{Cr-U}$ $[12.1]_{UC}$		590 ±20		134 ±12	
(52)	2530 ±50		18.0 ±1.1		410 ±20		117 ±10	
(53)	3050 ±150 $(2640)_G$ $(5700)_{Cr}$		21.5 ±0.8 $(20.1)_G$ $(20)_{Cr}$ $[6.1]_K$		570 ±20 $(454)_G$		63 ±15 $(79)_G$	
(54)	2440 ±50		21.0 ±0.8 $[5.4]_K$		470 ±20		103 ±10	
(55)	2790 ±60		18.2 ±0.6		450 ±20		87 ±11	
(56)	2490 ±50		20.8 ±1.3 (out)		1120 ±30 (out)		209 ±20	

Table 1--continued

No.	Type of Meteorite		Meteorite	Mass (g)	Na (ppm)	Na atoms/10^6 Si atoms	Sc (ppm)	Sc atoms/10^6 Si atoms	Cr (ppm)	Cr atoms/10^6 Si atoms
					Abundances					
(57)		Fa, Cc	Bjurböle	0.228	6980 ±150 (7000)$_{EU}$ (9200)$_{UC}$	44,300	8.6 ±0.5 (7.5)$_{G}$	28	3650 ±40 (4040)$_{UC}$ (3060)$_{G}$	10,200
(58)		Fa, Cia	Bori	0.112	7340 ±150		8.1 ±0.6		3620 ±40	
(59)		Fa, Ccb	Bremerwörde	0.298	6700 ±150 (8800)$_{Cr}$		9.4 ±0.9		4850 ±50 (1400)$_{Cr}$	
(60)		Fa	Bruderheim	0.200	6520 ±150 (7300)$_{D}$	43,000	8.4 ±0.8	28	4550 ±90 (3600)$_{D}$	13,200
(61)		Fa, Ckb	Ensisheim	0.249	6080 ±120 (2800)$_{Cr}$		8.8 ±0.9		4200 ±60	
(62)		Fa, Ceb	Farmington	0.307	5460 ±110 (5400)$_{Cr}$		7.4 ±0.6 (6.0)$_{G}$		3520 ±60 (2720)$_{G}$ (4000)$_{Cr}$	
(63)		Fa	Harleton	0.306	7350 ±150		8.8 ±0.6		3820 ±40	
(64)		Fa, Cck	Holbrook	0.319	5970 (6900)$_{MW}$ (7300)$_{EU}$	38,700	8.2 (8.2)$_{S}$ (9.7)$_{BPH}$ (9.2)$_{G}$	27	3730 (3100)$_{MW}$ (3840)$_{G}$ (2100)$_{BPH}$	10,700
(65)		Fa, Cgb	Homestead	0.0297	7560 ±160 (6800)$_{UC}$ (11,000)$_{Cr}$	50,000	7.6 ±0.9 (6.2)$_{G}$	26	4000 ±80 (2200)$_{UC}$ (1920)$_{G}$	11,700
(66)		Fa, Cgc	Khohar	0.173	7480 ±150		8.1 ±0.6 (10.6)$_{G}$		3900 ±70 (4020)$_{G}$	
(67)		Fa, Cwa	Kyushu	0.139	6520 (5400)$_{MW}$	42,500	8.2 (8.5)$_{S}$	30	3570 (3700)$_{MW}$	10,300
(68)		Fi, Ci	Lake Labyrinth	0.425	7140 ±140		8.2 ±0.5 (6.6)$_{G}$		3950 ±60 (3170)$_{G}$	
(69)		Fa, Cw	Leedey	0.294	5790		10.1		3250	
(70)		Fi, Cs	McKinney	0.256	5420 (5600)$_{W}$	35,500	7.9	26	3610 (3490)$_{W}$	10,400
(71)		Fa, Cwa	Mocs	0.484	6110 ±120 (7100)$_{EU}$ (8900)$_{Cr}$		6.9 ±0.8 (15.9)$_{G}$		3880 ±40 (3870)$_{G}$ (7200)$_{Cr}$	
(72)		Fa, Cwa	Modoc	0.167	5700 (3300)$_{UC}$	33,700	8.2 (8.1)$_{S}$ (9.2)$_{BPH}$	25	3010 (2300)$_{BPH}$	7850
(73)		Fa, Cg	Paragould	0.427	7300 ±140 (4900)$_{Cr}$		8.1 ±0.5		3970 ±40	
(74)		Fa	Peace River	0.316	7050 ±140		9.0 ±0.6		4900 ±50	
(75)		Fa, Cw	Perpeti	0.143	7070 ±140 (8700)$_{UC}$	47,000	8.5 ±0.9 (7.0)$_{G}$	29	4510 ±90 (2770)$_{G}$ (4500)$_{UC}$	13,300
(76)		Fa, Cw	St. Michel	0.230	5250 ±100 (9800)$_{UC}$	35,000	8.6 ±0.6 (10.7)$_{G}$	29	3520 ±70 (3820)$_{G}$ (3800)$_{UC}$	10,300
(77)		Fa, Cwa	Tenham	0.169	6850 ±130		11.2 ±0.9 (10.8)$_{G}$		3650 ±70 (3350)$_{G}$	
(78)		Fi	Walters	0.344	6560 ±130		9.0 ±0.6		3800 ±40	
(79)		Fi, Cs	Wickenburg	0.538	6760 ±130		8.9 ±0.6		3700 ±60	
			Average[h]		6780 ±620	44,800 ±4100	8.7 ±0.9	29 ±3	3860 ±310	11,200 ±900
(80)	Amphoteric	Fa, CAmb	Manbhoom	0.173	6200 (3260)$_{UC}$	40,300	8.4 (8.8)$_{S}$	28	3460 (3800)$_{UC}$	9950
(81)		Fa, CAmb	Vavilovka	0.314	6070 (12,000)$_{UC}$	39,600	7.8	26	3630 (1030)$_{UC}$	10,500
			Average		6130 ±70	40,000 ±400	8.1 ±0.4	27 ±1	3540 ±80	10,200 ±300
(82)	Enstatitic	Fa, Cck	Indarch, A	0.170	6700 } 7400 ±700 (7500)$_{W}$	49,500 } 54,400 ±4900	6.3 (5.3)$_{S}$	24	3050 (2500)$_{G}$ (3220)$_{W}$	9980 } 10,300 ±300
(83)			Indarch, B	0.160	8030 ±160	59,300	6.2 ±0.8 (6.7)$_{G}$	23	3240 ±60	10,600
(84)		Fa, Cec	Khairpur	0.179	6200 ±120 (5900)$_{UC}$	37,900	10.8 ±0.8 (5.6)$_{G}$	34	3600 ±70 (1800)$_{UC}$	9740
(85)		Fa, Cec	St. Marks	0.329	5530 (6300)	37,600	5.5 (7.2)$_{S}$ (11.3)$_{G}$	19	3070 (3600)$_{G}$	9250
			Average		6400 ±710	43,300 ±7400	7.7 ±2.1	25 ±6	3270 ±220	9760 ±360
(86)	Ca-rich achondritic	Fa, Eub	Juvinas	0.252	2520 (3300)$_{UC}$	13,400	29 (28)$_{S}$ (32)$_{G}$	79	2100 (2100)$_{UC}$ (1600)$_{G}$	4960
(87)		Fa, Eu	Moore County	0.228	3020 (3300)$_{UC}$ (3500)	16,300	24 (23)$_{G}$	66	1930 (3020)$_{UC}$ (3100)$_{G}$	4600
(88)		Fa, Eub	Stannern	0.463	3380 (4500)$_{UC}$ (5600)	18,400	32 (31)$_{S}$ (48)$_{G}$	89	1780 (1920)$_{D}$ (2300)$_{G}$ (2400)$_{UC}$	4300
(89)		Fi, Ho	Nuevo Laredo	0.177	3900 (3000) (4170)	20,600	38 (43)$_{S}$ (43)$_{BPH}$	102	1810 (1990)$_{D}$ (1100)$_{BPH}$	4220
(90)		Fa, Ho	Petersburg	0.241	3000 (6100)$_{UC}$	15,800	29	78	2750	6430
(91)		Fa	Kapoeta (light phase)	0.240	1720		21		4170 (out)	
			Average		3000 ±530	17,000 ±2000	29 ±5	83 ±10	2100 ±300	4900 ±600
(92)		Fa, Nak	Nakhla	0.270	3650 ±80 (3000)$_{UC}$	19,500	53 ±1 (54)$_{S}$ (49)$_{G}$	145	1820 ±40 (2300)$_{UC}$ (1900)$_{G}$	4180
(93)	Ca-poor achondritic	Fa, Bu	Bishopville, A	0.429	6560 ±120 (8000)$_{UC}$	30,000	6.5 ±0.2 (11)$_{G}$	15	260 ±10 } (460)$_{G}$	520
(94)			Bishopville, B	0.468	9920 ±200 (10,000)$_{EU}$	45,300	6.1 ±0.2	14	250 ±10	500
(95)		Fa, Bu	Norton County	0.194	450 (740)$_{UC}$	2060	9.6 (9.0)$_{S}$	23	570 (820)$_{UC}$	1160
(96)		Fa, Bu	Pena Blanca Springs	0.167	1240	5660	5.2	12	370	730
			Average				7.0 ±1.7	17 ±5	400 ±120	800 ±260
(97)	Mesosideritic	Fa, M	Estherville	0.406	1690		17 (18)$_{S}$		5660	
(98)		Fi, M	Vaca Muerta	0.562	1360 ±30		14.8 ±0.9		1560 ±30	
		Average			1530 ±170		16 ±1		3500 ±2000	
(99)	Pallasitic	Fi, Pa	Brenham	0.148	79		1.2 (0.8)$_{S}$		160	
(100)		Fa, Pa	Marjalahti	0.494	120		1.6		400	
(101)		Fi, Pa	Phillips County	0.467	220 ±10 (out)				3820 ±80 (out)	
(102)		Fa, Pa	Salta	0.273	85		1.5		290	
			Average		95 ±17		1.4 ±0.2		280 ±80	
(103)	Terrestrial Basalts[i]		Columbia Plateau	0.349 (>50)	18,700		46 (37)$_{S}$		<90	
(104)			Kilauea iki-22	0.494 (>50)	10,400 (11,300)$_{Mur}$	58,200	25 (23)$_{S}$	71	1210	2990
(105)			Mid-Atlantic G. E. 159	0.272 (>50)	18,500 ±400		47 ±3		340 ±10	
(106)			Mid-Atlantic G. E. 260	0.477 (>50)	18,800 ±400		38 ±3		79 ±5	
			Average		16,600 ±3100		38 ±7			
(107)	Eclogites[i]		R-117	0.259 (5)	10,400		42 (48)$_{S}$		530	
(108)			RV-3	0.361 (10)	5370		57 (43)$_{S}$		2380	
(109)	Peridotites[i]		Wesselton Mine W. S. S. I.	0.406 (10)	1420		13 (10.4)$_{S}$		2840	
(110)			R-80	0.237 (5)	480 ±30		13.4 ±0.5		2720 ±60	
(111)			Kimberlite R-275	0.195 (5)	980 ±40		11.8 ±0.5		1610 ±30	

[a]Abundances with (±) single standard deviations due to counting statistics only were calculated from peak areas of prominent gamma rays as given by a multichannel printer. Abundances with no error indication were calculated from peak heights of prominent gamma rays as plotted by a Moseley XY recorder and are generally accurate to better than ±10% (in most cases to ±5%). Gamma rays were: 15-h Na^{24}, 2.75 Mev; 85-d Sc^{46}, 2.01-Mev sum; 28-d Cr^{51}, 0.32 Mev; 2.56-h Mn^{56}, 0.85 Mev; 45-d Fe^{59}, 1.10 and 1.29 Mev; 5.3-y Co^{60}, 2.50-Mev sum; and 12.8-h Cu^{64}, 0.51-Mev annihilation.

[b]Fa and Fi indicate meteoritic fall and find as given by G. T. Prior's catalogue, the Nininger Meteorite Catalogue, and the Urey and Craig tables. Classification after Rose-Tschermak-Brezina (see Urey and Craig[12]).

[c]Replicate analyses performed on meteoritic samples are designated by A, B, etc.

[d]Contributions of 1.17- and 1.33-Mev γ of Co^{60} and 1.12-Mev γ of Sc^{46} were subtracted from composite peaks of Co^{60}, Sc^{46}, and 1.10- and 1.29-Mev γ of Fe^{59}. See text for details. Values in brackets indicate the metallic content obtained by other workers.

Table 1--continued

	Mn (ppm)	Mn atoms/10^6 Si atoms	Fe (%)	Fe atoms/10^6 Si atoms ($\times 10^5$)	Co (ppm)	Co atoms/10^6 Si atoms	Cu (ppm)	Cu atoms/10^6 Si atoms
	Abundances							
(57)	2860 ±140 (930)$_{UC}$ (2240)$_{MB}$	7590	21.6 ±0.8 (20.6)$_{UC}$ (20.0)$_G$ [6.4]$_{UC}$	5.6	520 ±20 (400)$_{UC}$ (371)$_G$	1290	178 ±16 (92)$_G$	410
(58)	2750 ±50		23.9 ±1.1		710 ±20		154 ±18	
(59)	2550 ±50		23.9 ±0.9 (25.1)$_{Cr}$		610 ±20		105 ±10	
(60)	2800 ±50 (2500)$_D$	7730	(22.3)$_D$		440 ±20	1130	----	
(61)	2440 ±130 (1600)$_{Cr}$		26.5 ±1.3 (20.7)$_{UC}$ (34.7)$_{Cr-U}$ [6.7]$_{UC}$ [3.2]$_K$		870 ±30		98 ±13	
(62)	2250 ±90 (2760)$_G$ (1200)$_{Cr}$		24.2 ±0.9 (22.1)$_{UC}$ (22.7)$_G$ (22.1)$_{Cr}$ [9.9]$_{UC}$ [7.6]$_K$		850 ±30 (532)$_G$		62 ±10 (57)$_G$	
(63)	3200 ±190		27.9 ±0.9		670 ±20		81 ±10	
(64)	2870 (2480)$_{MB}$ (2900)$_{MW}$ (2710)$_G$ (1700)$_{Cr}$				390 (520)$_{MW}$ (456)$_G$	990	(114)$_G$ (96)$_{MW}$	
(65)	3000 ±150 (550)$_{UC}$ (2570)$_G$	8300	15.9 ±1.2 (out)(23.3)$_{UC}$ (22.8)$_G$ (32)$_{Cr-U}$ (24.1)$_{Cr}$ (21.6)$_{MW}$ (21.0)$_G$ [9.7]$_{UC}$ [18.4]$_K$		400 ±20 (out) (900)$_{UC}$ (710)$_G$		185 ±50 (67)$_G$	
(66)	2190 ±199 (2550)$_G$		21.6 ±1.0 (23.0)$_G$		590 ±20 (552)$_G$		93 ±14 (112)$_G$	
(67)	3880 (2600)$_{MW}$	10,600	(22.0)$_{MW}$		420 (460)	1070	----	
(68)	2880 ±150 (2560)$_G$		18.4 ±0.7 (20.3)$_G$		430 ±20 (435)$_G$		44 ±9 (112)$_G$	
(69)	2730				360		----	
(70)	2850 (2400)$_W$ (2600)$_{MB}$	7820	(14.8)$_{Cr}$ (21.2)$_W$ [7.8]$_W$		460 (400)$_W$	1200	----	
(71)	2150 ±120 (2700)$_{MB}$ (2450)$_G$ (8700)$_{Cr}$		26.3 ±1.3 (out) (22.1)$_G$ (24.5)$_{Cr-U}$ [5.9]$_K$		1080 ±20 (out)(648)$_G$		93 ±8 (157)$_G$	
(72)	2690 (800)$_{UC}$ (2700)$_{MB}$	6440	(18.5)$_{UC}$		440 (300)$_{UC}$	1000	----	
(73)	2880 ±140		19.2 ±0.6 (19.8)$_{Cr}$		460 ±20		77 ±8	
(74)	2420 ±120		17.5 ±0.8		610 ±20		51 ±7	
(75)	2390 ±120 (2100)$_{UC}$ (2480)$_G$	6650	24.9 ±1.2 (out) (25.4)$_G$ (22.5)$_{UC}$ [7.0]$_{UC}$	6.8	1020 ±40 (out) (500)$_{UC}$ (746)$_G$	2610	105 ±17 (95)$_G$	250
(76)	2640 ±130 (3200)$_{UC}$ (3220)$_{MB}$ (2560)$_G$	7310	20.9 ±0.9 (22.2)$_{UC}$ (21.8)$_G$ [7.8]$_{UC}$	5.7	670 ±20 (1300)$_{UC}$ (598)$_G$	1730	175 ±18 (93)$_G$	420
(77)	2590 ±130 (2440)$_G$ (3900)$_{Cr}$		19.0 ±1.0 (21.1)$_G$ (21.2)$_{Cr-U}$		610 ±20 (594)$_G$		98 [illegible] (110)$_G$	
(78)	2540 ±120		19.7 ±0.6		500 ±20		83 ±8	
(79)	2740 ±140		21.8 ±0.8		580 ±20		129 ±13	
	2670 ±220	7370 ±610	21.1 ±2.4 (19)	5.8 ±0.7	540 ±120 (24)	1390 ±300	109 ±33 (24)	260 ±80
(80)	2970 (500)$_{UC}$	8050	(20.9)$_{UC}$		250	630	----	
(81)	3010 (6000)$_{UC}$	10,600	(20.3)$_{UC}$		330 (500)$_{UC}$	830	----	
	2990 ±20	9300 ±1300			290 ±40	730 ±100		
(82)	2790 } 2740 ±60 (1000)$_W$ (1000)$_{Cr}$ (2190)$_G$	8630 } 8460 ±180			810 } 840 ±30 (800)$_W$	2940 } 2710 ±240	----	----
(83)	2680 } ±150	8280 }	29.1 ±1.5 (30.5)$_G$ (30.4)$_{Cr}$ (33.8)$_W$ [24.1]$_W$		860 ±30 } (8.62)$_G$ (590)$_{Cr}$	2470 }	156 ±17 (255)$_G$	420
(84)	2760 ±100 (2450)$_G$	7060	25.6 ±1.0 (23.5)$_{UC}$ (36.2)$_G$ [16.8]$_{UC}$		1000 ±20 (1700)$_{UC}$ (1280)$_G$	2390	124 ±17 (137)$_G$	280
(85)	2100 (2560)	5980	(31.6)$_{UC}$		750 (2100)	1980	(202)$_G$	----
	2530 ±290	7170 ±900	(28.8 ±2.1)$_{TP\ and\ UC}$		860 ±90	2360 ±220	140 ±16	350 ±70
(86)	4640 (1600)$_{UC}$ (4040)$_D$	10,300	(14.8)$_{UC}$ [Tr]$_{UC}$		4	7		
(87)	3230 (2400)$_{UC}$ (3130)$_G$	7330	(12.2)$_{UC}$ (12.7)$_G$		3 (<5)$_G$	6	----	
(88)	4280 (3870)	9750	(14.4)$_{UC}$ [Tr]$_{UC}$		4	8	----	
(89)	4310 (4300)$_D$	9510	(15.9)$_D$		~2	~4	----	
(90)	3590	7910	(16.4)$_{UC}$ [0.50]$_{UC}$		54	113	----	
(91)	2840				24		----	
	3820 ±600	9000 ±1100	(14.7 ±1.2)$_{UC\ and\ D}$					
(92)	---- (3490)$_G$		16.4 ±0.6 (16.2)$_{UC}$ (16.2)$_G$	3.6	43 ±4 (32)$_G$	89	----	
(93)	2200 ±50 } 1500 ±700 (1140)$_G$ (1520)$_{UC}$	4200	0.7 ±0.1 (1.0 ±0.2)$_{UC}$	0.13	3.1 ±0.5 (8.9)$_G$	6	4 ±12 (2.6)$_G$	6
(94)	800 ±30 }	1530	0.9 ±0.1 (0.56)$_G$	0.17	2.1 ±0.4	4	<10	<16
(95)	1710 (1200)$_{MB}$ (1240)$_W$ (650, 3000)$_{UC}$	3290			4	8	----	
(96)	1090	2060			4	8	----	
	1430 ±230	2700 ±460						
(97)	3510		9.4		45 (1120)$_{Sm}$		----	
(98)	2070 ±100		39.3 ±1.6		1290 ±40		107 ±6	
	2790 ±720							
(99)	1610				5		----	
(100)	2130				9		----	
(101)	650 ±30 (out)		40.7 ±2.0		1860 ±60 (out)		164 ±7	
(102)	2150				6			
	1960 ±240				7 ±2			
(103)	2970 (~1300)				----		----	
(104)	2160 (1300)$_{Mur}$	5050	(9.1)$_{Mur}$		65			
(105)	----		9.5 ±0.6		45 ±3	140	45 ±45	
(106)	----		9.0 ±0.4		43 ±3		45 ±32	
	2500 ±400		9.2 ±0.2		51 ±9			
(107)	2590				58		----	
(108)	2560				47		----	
(109)	1200		---		110		----	
(110)	1080 ±60		5.1 ±0.4		120 ±6		88 ±10	
(111)	1040 ±50		7.6 ±0.4		82 ±5		124 ±12	

[e]Contributions of 0.51-Mev annihilation γ due to 15-h Na^{24}, the principal contributor, have been subtracted. See text for details.

[f]Values obtained by other workers are given in parentheses and accompanied by subscript initials of workers: EU = Edwards and Urey;[14] G = Greenland;[25] W = Wiik;[16] D = Duke;[29] MB = Moore and Brown;[18] BPH = Bate, Potratz, and Huizenga;[30] S = Schmitt, et al.,[2] UC = Urey and Craig;[12] MW = Mason and Wiik;[31] C = Chodos;[32] TP = this paper; Mur = Murata;[33] Cr = Craig;[34] A = Aaramae;[35] Sm = Smales.[9] Values of others were generally not obtained on specimens of this work.

[g]Averages are only from meteoritic falls and from this work and from Schmitt.[8] (out) indicates that values were not included in averages. If the sample weight was less than 0.1 g, or the Co abundance in the L-group was >1000 ppm, these Fe and Co abundances were not included in the averages.

[h]Average atomic values calculated from average abundances (in ppm) and the Urey-Craig[12] SiO_2 values of 39.5% and 36.2% for L- and H-group ordinary chondrites. Only "falls" constitute averages.

[i]Weights of samples are aliquots taken from masses given in parentheses after analyzed weights.

Table 2

AVERAGE METEORITIC AND TERRESTRIAL ABUNDANCES OF Na, Sc, Cr, Mn, Fe, Co, AND Cu[a]

Type of Meteorite	Abundances[a] Na (ppm) (×10³)	Na atoms/10⁶ Si atoms (×10³)	Sc (ppm)	Sc atoms/10⁶ Si atoms	Cr (ppm) (×10³)	Cr atoms/10⁶ Si atoms (×10³)	Mn (ppm) (×10³)	Mn atoms/10⁶ Si atoms (×10³)	Fe[b] (%)	Fe atoms/10⁶ Si atoms (×10⁵)	Co (ppm)	Co atoms/10⁶ Si atoms	Cu (ppm)	Cu atoms/10⁶ Si atoms
Chondritic														
2 carbonaceous Type I	5.3 ±0.2[c]	61 ±2	5.3 ±0.2	32 ±1	2.6 ±0.2	13.2 ±1.1	1.82 ±0.07	8.8 ±0.3	17.7 ±0.9	8.4 ±0.5 ——	—500 ±30	2230 ±[illegible]	118 ±[illegible]	490
4 carbonaceous Type II	4.3 ±0.4	40 ±3	9.4 ±0.9	44 ±2	3.1 ±0.2	12.8 ±0.4	1.75 ±0.10	6.8 ±0.4	20.4 ±1.4	-----	550 ±70	2000 ±200	—→—	-----
6 carbonaceous Type III	3.6 ±0.7	28 ±6	10.5 ±0.8	42 ±7	3.5 ±0.1	12.0 ±0.4	1.69 ±0.10	5.6 ±0.3	22.4 ±3.2	-----	610 ±80	1820 ±180	120 ±30	-----
20 H-group ordinary[d]	6.2 ±0.5	45 ±3	8.3 ±1.0	31 ±4	4.0 ±0.3	12.7 ±1.0	2.43 ±0.13	7.3 ±0.5	25.9 ±2.1 (15)	7.7 ±0.6	960 ±90 (16)	2410 ±250	100 ±10 (19)	260 ±30
29 L-group ordinary[d]	6.8 ±0.6	45 ±4	8.7 ±0.9	29 ±3	3.9 ±0.3	11.2 ±0.9	2.67 ±0.22 (28)	7.4 ±0.6	21.1 ±2.4 (19)	5.8 ±0.7	540 ±120 (24)	1390 ±300	109 ±33 (24)	260 ±40
2 LL-group amphoterites	6.1 ±0.1	40 ±0.5	8.1 ±0.4	27 ±1	3.5 ±0.1	10.2 ±0.3	2.99 ±0.02	9.3 ±1.3	$[20.6 \pm 0.3]_{UC}$	-----	290 ±40	730 ±100	-----	-----
3 enstatites	6.4 ±0.7	43 ±7	7.7 ±2.1	25 ±6	3.3 ±0.2	9.8 ±0.4	2.53 ±0.29	7.2 ±0.9	$[28.8 \pm 2.1]_{TP+UC}$	-----	860 ±90	2360 ±220	140 ±16	350 ±70
Nonchondritic														
5 Ca-rich achondrites[e]	3.0 ±0.5	17 ±2	29 ±5	83 ±10	2.1 ±0.3	4.9 ±0.6	3.8 ±0.6	9.0 ±1.1	$[14.7 \pm 1.2]_{UC+D}$	-----	2 to 54	4 to 113	-----	-----
3 Ca-poor achondrites	0.5 to 9.9	2 to 45	7.0 ±1.7	17 ±5	0.40 ±0.12	0.80 ±0.26	1.4 ±0.2	2.7 ±0.5	-----	-----	4 ±1	7 ±1	-----	-----
2 mesosiderites	1.5 ±0.2	----	16 ±1	——	3.5 ±2.0	-----	2.8 ±0.7	-----	9 to 39	-----	45 to 1290	-----	-----	-----
4 pallasites	0.095 ±0.017	----	1.4 ±0.2	----	0.28 ±0.08	-----	2.0 ±0.2	-----	-----	-----	7 ±2	-----	-----	-----
Terrestrial specimens														
4 basalts	16.6 ±3.1	----	38 ±7	----	<0.1 to 1.2	-----	2.5 ±0.4	-----	9.2 ±0.2	-----	51 ±9	-----	-----	-----
2 eclogites	7.8 ±2.6	----	47 ±3	----	1.4 ±0.9	-----	2.6 ±0.1	-----	-----	-----	53 ±6	-----	-----	-----
2 peridotites	0.9 ±0.5	----	13 ±1	----	2.7 ±0.1	-----	1.1 ±0.1	-----	-----	-----	110 ±10	-----	-----	-----
1 kimberlite	1.0	----	12	----	1.6	-----	1.0	-----	-----	-----	82	-----	-----	-----

[a]Average values calculated from INNA values of this work given in Table 1.
[b]Values obtained by other workers are given in brackets and accompanied by subscript initials of workers: UC = Urey and Craig;[12] D = Duke;[29] TP = this paper.
[c]Only Orgueil and Ivuna constitute average for Type I carbonaceous meteorites.
[d]Where less than 20 H- and 29 L-group chondrites are averaged, the number in parentheses indicates the averaged number of chondrites.
[e]Nakhla has been excluded.

Table 3

ABUNDANCES OF Na, Sc, Cr, Mn, Fe, Co, AND Cu IN H- AND L-GROUP ORDINARY CHONDRITES, CLASSIFIED BY ROSE-TSCHERMAK-BREZINA SYSTEM[a]

Chondritic Subclass	Abundance													
	Na (ppm)($\times 10^3$)		Sc (ppm)		Cr (ppm)($\times 10^3$)		Mn (ppm)($\times 10^3$)		Fe[b] (%)		Co[b] (ppm)($\times 10^2$)		Cu (ppm)	
	H	L	H	L	H	L	H	L	H	L	H	L	H	L
White	-----	6.2 ±0.5 (7)	-----	8.8 ±1.0 (7)	-----	3.6 ±0.4 (7)	-----	2.7 ±0.3 (9)	-----	21.2 ±1.8 (5)	-----	5.0 ±1.1 (5)	-----	118 ±29 (4)
Intermediate	5.9 ±0.5 (2)	7.5 ±0.7 (3)	8.6 ±0.3 (2)	8.3 ±0.1 (3)	3.7 ±0.1 (2)	3.7 ±0.1 (3)	2.3 ±0.1 (2)	2.6 ±0.1 (3)	23.5 ±1.2 (1)	21.6 ±1.5 (3)	8.7 ±0.2 (1)	5.4 ±1.1 (3)	91 ±4 (2)	114 ±26 (3)
Grey	6.1 ±0.4 (9)	7.2 ±0.3 (5)	8.6 ±0.8 (9)	8.4 ±0.5 (5)	4.0 ±0.4 (9)	4.0 ±0.1 (5)	2.4 ±0.2 (9)	2.8 ±0.3 (5)	25.8 ±1.9 (8)	18.5 ±2.1 (3)	8.6 ±1.0 (8)	5.1 ±0.5 (3)	105 ±11 (8)	101 ±32 (5)
Spherical	6.2 ±0.3 (3)	6.9 ±0.1 (4)	8.2 ±0.7 (3)	8.3 ±0.7 (4)	4.1 ±0.4 (3)	4.0 ±0.5 (4)	2.5 ±0.1 (3)	2.7 ±0.1 (3)	27.7 ±2.1 (2)	21.7 ±1.1 (4)	8.2 ±0.8 (2)	5.5 ±0.5 (4)	102 ±6 (3)	124 ±32 (4)
Crystalline spherical and crystalline	6.4 ±0.4 (2)	6.0 ±0.1 (2)	6.7 ±0.1 (2)	8.5 ±0.3 (2)	3.9 ±0.1 (2)	4.0 ±0.2 (2)	2.4 ±0.1 (2)	2.7 ±0.2 (2)	26.3 ±1.2 (2)	24.0 ±2.5 (2)	9.4 ±1.0 (2)	6.3 ±2.4 (2)	116 ±9 (2)	98 ±13 (1)
Black	8.1 ±0.2 (1)	6.4 ±1.0 (2)	5.9 ±0.6 (1)	8.4 ±1.0 (2)	3.8 ±0.1 (1)	3.8 ±0.3 (2)	2.6 ±0.1 (1)	2.5 ±0.2 (2)	-----	21.9 ±2.3 (2)	-----	5.9 ±2.5 (2)	95 ±20 (1)	71 ±9 (2)

[a] Values were calculated from INAA values of this work given in Table 1. Number in parentheses below each average indicates the number of chondrites constituting the average.

[b] Values are those of this work given in Table 1 (values followed by (out) have not been included). Where no INAA values were given, abundances from Wiik[16] and Mason and Wiik[31] were included.

Table 4

ABUNDANCES OF Na, Mn, AND Cu IN INDIVIDUAL CHONDRULES OF ALLEGAN (BRONZITIC CHONDRITE) DETERMINED BY INAA[a]

Chondrule	Mass (mg)	Abundance: Na (ppm)	Sc (ppm)	Cr (ppm)	Mn (ppm)	Fe (%)	Co (ppm)	Cu (ppm)
1	0.440	5590 ±180	11.1 ±1.1	2180 ±220	3130 ±60	7.5 ±0.8	66 ±7	57 ±24
2	0.444	9100	10.1 ±1.0	3440 ±300	3100	6.3 ±0.6	51 ±5	<28
3	0.521	9460	10.6 ±1.2	2040 ±200	2930	5.3 ±0.5	131 ±14	<30
4	0.570	7350	19.7 ±1.8	2160 ±160	2890	6.4 ±1.0	3 ±5	
5	0.625	5440	4.1 ±0.8	2080 ±160	3240	8.5 ±0.8	41 ±6	
6	0.856	7050			2840			
7	0.885	7630			2700			50 ±19
8	0.915	5280			2970			53 ±17
9	1.035	(15,000)			2590			
10	1.125	10,200			2800			
Average		7460 ±1460			2920 ±160			
11	1.225	7500	26 ±1	2210 ±40	2890	5.0 ±0.4	7 ±3	
12	1.270	8400			3130			
13	1.305	7800			3130			10 ±15
14	1.33	(3620)			3110			47 ±12
15	1.49	6730			3130			3 ±15
16	1.75	5900	9.6 ±1.3	3020 ±40	3130	10.9 ±1.6	35 ±28	48 ±12
17	2.33	7930	10.5 ±1.0	3830 ±40	3040	8.5 ±1.1	59 ±18	
18	2.71	7830	16.2 ±1.0	3300 ±30	2680	10.0 ±0.6	94 ±15	12 ±12
19	2.97	7760	7.6 ±0.8	1490 ±20	2800	15.2 ±0.3	72 ±14	46 ±11
20	3.93	7050	19.3 ±0.8	2100 ±30	3070	10.2 ±0.5	27 ±12	21 ±10
Average		7430 ±580			3010 ±130			
Over-all average		7450 ±1020			2970 ±150			
Whole chondrite	1730	5730 ±260	8.1 ±0.6	3640 ±150	2380 ±110	29.8 ±1.9	900 ±110	105 ±20

[a]Abundances were calculated from peak areas of principal gamma rays (see footnote a of Table 1) as given by a multichannel printer. Errors are one standard deviation due to counting statistics only. For Na, Cr, and Mn, the errors of individual analyses are all approximately ±2% to 3%. Values in parentheses are not included in averages.

Table 5

ABUNDANCES OF Na, Sc, Cr, Mn, Fe, Co, AND Cu IN INDIVIDUAL CHONDRULES OF OCHANSK (BRONZITIC CHONDRITE) DETERMINED BY INAA[a]

Chondrule	Mass (mg)	Abundance						
		Na (ppm)	Sc (ppm)	Cr (ppm)	Mn (ppm)	Fe (%)	Co (ppm)	Cu (ppm)
1	0.275	(19,700) ±400	24.2 ±1.5	2280 ±130	2400 ±50	1.6 ±1.0	21 ±21	-----
2	0.288	8450			3130			
3	0.412	7310	13.8 ±1.4	960 ±100	3250	2.8 ±0.3	18 ±12	-----
4	0.612	9280			3020			
5	0.679	5650			3370			
Average		7680 ±1180			3030 ±210			
6	1.79	8310			3080			
7	2.54	8070			2690			
8	2.63	7210	17.8 ±0.8	1990 ±80	2900	7.5 ±0.3	28 ±4	-----
9	2.93	6110	9.7 ±0.5	2410 ±100	3140	5.6 ±0.4	25 ±5	-----
10	2.93	(11,400)			2920			
Average		7430 ±770			2950 ±130			
11	5.51	7040	20.7 ±1.0	2550 ±60	2860	8.4 ±0.7	<7	35 ±21
12	6.09	5870	14.4 ±0.7	3550 ±40	3010	4.6 ±0.6	32 ±5	55 ±17
13	6.45	6210	9.1 ±2.2	2800 ±60	2950	13.0 ±0.9	<40	35 ±17
14	7.27	7070	9.9 ±0.6	3530 ±40	3480	7.7 ±0.6	42 ±6	68 ±19
15	7.66	7890	18.2 ±1.0	2840 ±50	2780	8.4 ±0.6	58 ±6	61 ±22
Average		6810 ±620	14.5 ±4.0	3050 ±390	3020 ±190	8.4 ±1.9		51 ±13
Magnetic								
16	6.8	4920	13.6 ±0.8	2570 ±50	3110	5.9 ±0.6	60 ±7	50 ±18
17	10.5	4860	11.9 ±0.5	2100 ±40	2660	7.8 ±0.4	54 ±5	29 ±14
18	13.7	5830	10.0 ±0.5	3340 ±60	2740	10.2 ±0.4	103 ±8	84 ±14
19	16.7	5630	9.2 ±0.5	2740 ±60	3060	10.3 ±0.3	38 ±4	109 ±13
20	20.5	6270	11.7 ±0.7	3020 ±60	2760	10.2 ±0.5	165 ±11	59 ±14
Average		5510 ±490	11.3 ±1.3	2750 ±340	2870 ±180	8.9 ±1.6	84 ±40	66 ±24
Over-all average		6850 ±760			2970 ±180			
Whole chondrite	307	6190 ±120	8.9 ±0.5	3840 ±40	2400 ±120	28.4 ±1.0	710 ±15	93 ±8

[a]See footnote (a) of Table 4.

Table 6

ABUNDANCES OF Na, Mn, AND Cu IN INDIVIDUAL CHONDRULES OF BJURBÖLE (HYPERSTHENIC CHONDRITE) DETERMINED BY INAA[a]

Chondrule	Mass (mg)	Abundance						
		Na (ppm)	Sc (ppm)	Cr (ppm)	Mn (ppm)	Fe (%)	Co (ppm)	Cu (ppm)
1	0.520	9770 ±150	11.7 ±0.8	4450 ±170	2910 ±60	12.5 ±0.7	206 ±15	
2	0.630	11,220	11.7 ±0.9	2730 ±120	2790	10.4 ±0.6	108 ±12	
3	0.665	11,780	10.9 ±0.8	2220 ±150	2740	11.4 ±0.7	22 ±8	
4	0.690	6310	13.2 ±0.8	2620 ±130	2730	9.1 ±0.7	37 ±10	120 ±21
5	0.775	8850	8.0 ±0.6	3630 ±150	2920	6.9 ±0.5	54 ±7	
6	0.810	9590	6.6 ±0.5	2740 ±120	3010	9.5 ±0.5	1 ±8	
7	0.820	9510	13.5 ±0.9	2690 ±150	2940	5.8 ±0.6	27 ±7	
8	0.850	8690	8.1 ±0.6	4460 ±180	3140	15.1 ±0.7	63 ±8	
9	0.855	6200	6.9 ±0.7	5310 ±200	2860	7.5 ±0.6	103 ±10	
10	0.920	9700	4.5 ±0.6	3090 ±150	2690	20.8 ±1.0	83 ±10	
11	0.935	8190			3020			
12	0.935	8860			3060			29 ±19
13	0.990	8130			3060			
Average		9000 ±1230			2920 ±120			
14	1.010	6720			3180			
15	1.020	9390			3100			
16	1.030	8160			2820			67 ±24
17	1.055	5350			2540			186 ±22
18	1.055	8760			2900			
19	1.060	9050			2960			
20	1.060	8830			3040			
21	1.065	6870			3200			21 ±14
22	1.130	7870			3120			
23	1.130	9350			2830			
24	1.135	8610			3090			
25	1.200	7960			2620			85 ±17
26	1.210	8250			2900			
27	1.220	5300			3210			<13
28	1.380	6450			3350			
29	1.495	10,150			2920			
30	1.625	8990			2660			96 ±15
Average		8000 ±1120			2970 ±180			
Over-all average	~1.0	8450 ±1200			2940 ±150			
Whole chondrite	228	6980 ±150	8.6 ±0.5	3650 ±40	2860 ±40	21.6 ±0.8	520 ±20	176 ±16

[a]See footnote (a) of Table 4.

Table 7

ABUNDANCES OF Na, Sc, Cr, Mn, Fe, Co, AND Cu IN INDIVIDUAL CHONDRULES OF CHAINPUR (TYPE III CARBONACEOUS CHONDRITE) DETERMINED BY INAA[a]

Chondrule	Mass (mg)	Abundance Na (ppm)	Sc (ppm)	Cr (ppm)	Mn (ppm)	Fe (%)	Co (ppm)	Cu (ppm)
1[b]	1.44	3740 ±80	8.9 ±1.5	3000 ±180	1370 ±30	7.1 ±1.6	500 ±40	68 ±12
2[b]	2.05	8290	8.3 ±1.6	4010 ±160	2360	14.9 ±1.5	500 ±40	83 ±14
3[b]	3.57	9680	9.8 ±1.0	4170 ±200	3030	9.3 ±1.2	280 ±30	62 ±12
4[b]	6.95	6480	10.9 ±1.4	4770 ±250	680	16.8 ±1.7	860 ±50	56 ±7
5[b]	14.08	3590	7.5 ±0.9	2910 ±150	830	22.9 ±1.2	960 ±60	172 ±8
Average		6360 ±2150	9.1 ±1.0	3770 ±650	1650 ±830	14.2 ±4.8	620 ±230	88 ±33
6	1.06	5480	6.1 ±0.9	3460 ±70	4460	7.1 ±0.8	92 ±15	17 ±14
7	2.05	6120	21.6 ±1.9	3870 ±240	3750	8.6 ±1.7	97 ±32	3 ±9
8	2.42	3980	14.4 ±1.5	3670 ±190	3480	3.0 ±1.8	115 ±38	8 ±8
9	2.45	10,100	10.4 ±1.2	4270 ±200	3950	3.2 ±1.1	49 ±25	0
10	2.72	7460	8.5 ±0.9	4900 ±250	4000	5.7 ±0.9	37 ±19	9 ±12
11	3.38	6160	8.5 ±1.5	4550 ±200	3160	7.8 ±1.9	310 ±30	51 ±10
12	5.10	7680	5.6 ±0.5	4110 ±200	1640	5.0 ±0.4	45 ±8	0
13	5.82	7290	13.2 ±1.0	3950 ±200	2010	9.7 ±0.9	420 ±30	0
14	5.97	5480	9.1 ±0.7	4120 ±200	3950	12.2 ±1.0	54 ±14	64 ±12
15	6.62	9310	8.2 ±0.9	4400 ±200	3840	6.0 ±0.5	26 ±18	0
16	7.14	7120	6.3 ±1.0	3940 ±200	2940	20.0 ±1.0	380 ±30	69 ±10
17	9.14	5910	10.4 ±0.7	4250 ±200	2750	7.8 ±0.4	12 ±7	0
18	13.9	8820	8.3 ±0.5	3830 ±200	3760	12.1 ±0.7	77 ±8	0
19	19.9	6630	6.3 ±0.7	3850 ±200	4280	16.0 ±1.1	132 ±13	9 ±9
20	30.9	1670	12.7 ±0.8	3460 ±180	1515	11.0 ±0.6	170 ±20	10 ±3
Average		6610 ±1530	10.0 ±3.1	4040 ±310	3300 ±780	9.0 ±3.6	134 ±99	0 to 69
Over-all average		6550 ±1690	9.8 ±2.6	3980 ±400	2910 ±790	10.3 ±3.9	260 ±130	0 to 172
Whole-rock matrix	320	7470 ±150	10.4 ±0.5	3450 ±70	2790 ±110	16.7 ±0.5	490 ±10	62 ±9
Ratio of chondrule (nonmagnetic) to chondrite		0.88	0.96	1.17	1.18	0.54	0.27	0 to 1.1

[a]Values were calculated from INAA values of this work given in Table 1.
[b]Magnetic.

Table 8

COMPARISON OF AVERAGE ABUNDANCES OF Na, Sc, Cr, Mn, Fe, Co, AND Cu IN CHONDRULES AND WHOLE-ROCK MATRICES OF CHAINPUR, ALLEGAN, OCHANSK, AND BJURBÖLE[a]

Chondrite	Abundance													
	Na (ppm)		Sc (ppm)		Cr (ppm)		Mn (ppm)		Fe (%)		Co (ppm)		Cu (ppm)	
	Chondrules	Matrix	Chondrules	Matrix	Chondrules	Matrix	Chondrules	Matrix	Chondrules	Matrix	Chondrules	Matrix	Chondrules	Matrix
Chainpur (Type III carbonaceous)	6550 ±1690	7470 ±150	9.8 ±2.6	10.4 ±0.5	3980 ±400	3450 ±40	2910 ±790	2790 ±110	10.3 ±3.9	16.7 ±0.5	260 ±130	490 ±10	0-172	62 ±9
Allegan (H group)	7450 ±1020	5730 ±260 (6220)[b]		8.1 ±0.6 (8.3)[b]		3640 ±150 (3990)[b]	2970 ±150	2380 ±110 (2430)[b]		29.8 ±1.9 (25.9)[b]		900 ±110 (860)[b]	3-57	105 ±20 (100)[b]
Ochansk (H group)	6850 ±760	6190 ±120 (6220)[b]		8.9 ±0.5 (8.3)[b]		3840 ±40 (3990)[b]	2970 ±180	2400 ±120 (2430)[b]		28.4 ±1.0 (25.9)[b]		710 ±15 (860)[b]	29-109	93 ±8 (100)[b]
Bjurböle (L group)	8450 ±1200	6980 ±150 (6780)[c]		8.6 ±0.5 (8.7)[c]		3650 ±40 (3860)[c]	2940 ±150	2860' ±40 (2670)[c]		21.6 ±0.8 (21.1)[c]		520 ±20 (540)[c]	<13-186	176 ±16 (109)[c]

[a]Average values from Tables 3 through 6.
[b]Average value of H-group ordinary chondrites from Table 1
[c]Average value of L-group ordinary chondrites from Table 1.

Table 9

CHECK OF INAA FOR Fe IN THE PRESENCE OF Co AND Sc

	Fe (mg)			Co (μg)			Sc (μg)		
Run	Present	Found	Present/Found	Present	Found	Present/Found	Present	Found	Present/Found
1	244	230	1.06	500	464	1.08	14.2	13.7	1.04
2	244	240	1.02	500	453	1.11	3.41	4.15	0.82
3	244	229	1.07	100	107	0.93	14.2	12.5	1.14
4	244	244	1.00	1000	918	1.09	14.2	12.6	1.13
5	122	113	1.08	500	498	1.00	28.4	27.6	1.03
6	122	121	1.01	500	478	1.05	14.2	12.9	1.10
7	122	117	1.04	500	497	1.01	3.41	3.30	1.03
8	61	58	1.05	500	496	1.01	28.4	26.9	1.06
9	61	57	1.07	500	486	1.03	14.2	13.0	1.09
10	61	54	1.13	500	504	0.99	3.41	3.4	0.99
11	61	58	1.05	100	104	0.96	14.2	14.0	1.01

REFERENCES

1. Urey, H. C., "Some Cosmochemical Problems," Notes on the Thirty-Seventh Annual Priestly Lectures, Pennsylvania State University, University Park, Pennsylvania, April 15-19, 1963.

2. Schmitt, R. A., et al., "Abundances of the Fourteen Rare-Earth Elements, Scandium and Yttrium in Meteoritic and Terrestrial Matter," Geochim. et Cosmochim. Acta, 27, 577 (1963).

3. Schmitt, R. A., 'Rare Earth, Yttrium and Scandium Abundances in Meteoritic and Terrestrial Matter," USAEC Report GA-4221, General Atomic Division, General Dynamics Corporation, May 15, 1963, 38p; Geochim. et Cosmochim. Acta, in press (in the journal article, the last section of GA-4221, "Proposed Shell Model for Parent Meteoritic Body," has been deleted, since the authors no longer believe in the validity of such a model (see Ref. 8)).

4. Fredriksson, K., "Chondrules on the Meteorite Parent Bodies," Trans. N. Y. Acad. Sci., Ser. II, 25, No. 7, 756-769 (1963).

5. Keil, K., and K. Fredriksson, "The Fe, Mg, Ca and Ni Distribution in Coexisting Numerals in the Murray Carbonaceous Chondrite," presented at the Annual Meeting of the Meteoritical Society of America, Socorro, New Mexico, 1962.

6. Wood, J. A., "Chondrules and the Origin of the Terrestrial Planets," Nature, 194, 127-139 (1962).

7. Wood, J. A., "Metamorphism in Chondrites," Geochim. et Cosmochim. Acta, 26, 739-749 (1962).

8. Schmitt, R. A., "Research on the Determination of Rare-earth Abundances in Meteorites; Additionally Includes Y, Sc, Cd, Na, Mn, Cu, Cr, Co, and Fe," General Atomic Report GA-4493, August 31, 1963, 25p.

9. Smales, A. A., D. Mapper, and A. J. Wood, "The Determination by Radioactivation of Small Quantities of Nickel, Cobalt, and Copper in Rocks, Marine Sediments and Meteorites," Analyst, 82, 75 (1957).

10. Prior, G. T., and M. H. Hey, Catalogue of Meteorites (2nd ed), British Museum of Natural History, 1953.

11. Mason, B. H., Meteorites, John Wiley and Sons, Inc., New York, 1962.

12. Urey, H. C., and H. Craig, "The Composition of the Stone Meteorites and the Origin of the Meteorites," Geochim. et Cosmochim. Acta, 4, 36 (1953).

13. Keil, K., private communication, 1963.

14. Edwards, G., and H. C. Urey, "Determination of Alkali Metals in Meteorites by a Distillation Process," Geochim. et Cosmochim. Acta, 7, 154 (1955).

15. Schmitt, R. A., and R. H. Smith, "Implication of Similarity in Rare-Earth Fractionation of Nakhlitic Meteorites and Terrestrial Basalts," Nature, 199, 550 (1963).

16. Wiik, H. B., "The Chemical Composition of Some Stoney Meteorites," Geochim. et Cosmochim. Acta, 9, 279 (1956).

17. Keil, K., "On the Phase Composition of Meteorites," J. Geophys. Res., 67, 4055 (1962).

18. Moore, C. B., and H. Brown, "The Distribution of Manganese and Titanium in Stony Meteorites," Geochim. et Cosmochim. Acta, 26, 495 (1962).

19. Engel, A. E. J., and C. G. Engel, "Hornblendes Formed During Progressive Metamorphism of Amphibolites, Northwest Adirondack Mountains, New York," Geol. Soc. Am. Bull. 73, 1499-1514 (1962).

20. Aller, L. H., "Abundances of Elements in Stars and Nebulae," University of Michigan Report AFOSR 3024, June, 1962.

21. Clayton, D. D., and W. A. Fowler, "Abundances of Heavy Nuclides," Ann. Phys., 16, No. 1, 51 (October, 1961).

22. Schmitt, R. A., R. H. Smith, and D. A. Olehy, "Cadmium Abundances in Meteorites and Terrestrial Matter," General Atomic Report GA-4167, May 20, 1963, 18p; Geochim. et Cosmochim. Acta, in press.

23. Nagy, B., W. G. Meinschein, and D. J. Hennessy, "Aqueous Low Temperature Environment of the Orgueil Meteorite Parent Body," Ann. N. Y. Acad. Sci., 108, 534 (1963).

24. Rowe, M. W., M. A. Van Dilla, and E. C. Anderson, "On the Radioactivity of Stone Meteorites," Geochim. et Cosmochim. Acta, 27, 983 (1963).

25. Greenland, L. P., doctoral dissertation, Australian National University, 1963.

26. Suess, H. E., H. Wänke, and F. Wlotzka, "On the Origin of Gas-Rich Meteorites," preprint, November, 1963.

27. Craig, H., "Petrological and Compositional Relationships in Meteorites," chapter of a text (in the "birthday series") dedicated to H. C. Urey on his seventieth birthday, 1963.

28. Mason, B., et al., "The Chainpur Meteorite," Am. Novitates Museum, in press, 1963.

29. Duke, M., doctoral dissertation, California Institute of Technology, 1963.

30. Bate, G. L., H. A. Potratz, and J. R. Huizenga, "Scandium, Chromium and Europium in Stone Meteorites by Simultaneous Neutron Activation Analysis," Geochim. et Cosmochim. Acta, 18, 101 (1960).

31. Mason, B., and H. B. Wiik, "The Miller, Arkansas Chondrite, The Kyushu, Japan Chondrite, The Holbrook, Arizona Chondrite," Geochim. et Cosmochim. Acta, 21, 266-283 (1960).

32. Chodos, A. A., data given by K. Fredrikkson and K. Keil, "The Light-Dark Structure in the Pantor and Kapoeta Stone Meteorites," Geochim. et Cosmochim. Acta, 27, 717 (1963).

33. Schmitt, R. A., and R. H. Smith, "A Program of Research for the Determination of Rare-earth Abundances in Meteorites. Quarterly Progress Report for the Period Ending December 15, 1961," General Atomic Report GA-2782 (Rev.), December 29, 1961, Table 1.

34. Craig, H., 1963 unpublished compilation of abundance data, inferior (considered as discards) to that given by Urey and Craig in Ref. 12. Values for Fe, for unweathered specimens, are denoted by Cr-U. Where more than one analysis was made, the average value is given.

35. Aaramae, A., quoted by K. Fredriksson, P. S. De Carli, and A. Aaramae in "Shock-induced Veins in Chondrites," preprint, 1963.

N64-19601

ERRATUM

GA-4782, ABUNDANCES OF Na, Sc, Cr, Mn, Fe, Co, AND Cu IN 92 METEORITES, 9 TERRESTRIAL SPECIMENS, AND 90 INDIVIDUAL CHONDRULES

by

R. A. Schmitt and R. H. Smith

December 17, 1963

The following erratum should be noted in General Atomic Report GA-4782:

Page 36, Table 6--

Abundance values of Sc, Cr, Fe and Co are not correlated with proper chondrule mass. For abundances of these elements, the sequence of chondrule masses should read 30, 25, 12, 16, 21, 27, 15, 4, 22 and 17. For example, the Cr abundance of 4450 ± 170 ppm in Table 6 as chondrule 1 corresponds to chondrule 30, mass 1.625 mg.

Corrected sequence will be listed in next quarterly report.

January 8, 1964